

**Environmental Impacts and Engineering Responses: Roman Ports and Salt Works**

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## **Introduction**

Sea installations during ancient times were important to the economy of the civilization that had them. Some installations, such as ports and harbors, were imperative for trading with other societies as well as bringing goods from distant lands across the sea. Other installations, like fishponds and salt works, were important for food production and preservation. The ancient Roman civilization had an abundance of ports and salt works at their disposal. This research will be examining the engineering response to the maintenance of these sea installations that depended on the environmental stability. Some of instabilities the Romans were battling was silting, or the accumulation of debris in harbors and rivers, as well as the rising of the sea level which especially affected salt works. This research also looks at who were the main benefactors of the upkeep of the installations and who performed it, and finally the reasons behind the end of maintenance and condition of the sites today. The majority of the research is examining the era of the Romans with some medieval and modern examples to understand how ancient history has impacted the modern world. Research today has shown that ancient ports such as Ostia and Portus in Italy, have battled silting through most of their operational period. There has also been evidence for flooding of salt works due to rising sea level, an example of this is in a Roman Villa in Soline Bay in Croatia.

## **Ports and Harbors**

Harbors have been used by multiple different civilizations across the Mediterranean. Some of the earliest harbors date back to 530 BC in the Aegean Sea. The engineering of harbors has been attributed to the Greeks since the 6<sup>th</sup> century BC and then eventually the Romans. There has been evidence that the Phoenicians have contributed to some of the architecture that were used on these harbors. As these maritime states and cities grew, so did the need for larger and more improved facilities for importing goods and docking ships (Lancaster 2009, 6-8). Often, when Romans conquered a new land, the ports that were already established became a part of the Roman Empire. These ports were used as points for off-loading cargo on trade routes that stretched throughout the empire.

There were various types of ports and harbors. Some were natural and others were artificial and built in wood or stone. Ideally, artificial harbors were used for larger ships that required more infrastructure for the off-loading process. Some of the infrastructure that was needed were

moles and deep-water quays, which made the harbor more desirable for the larger ships as well as ships with valuable cargo. Artificial harbors were not needed for smaller ships because they could be beached and off-loaded from land (Greene 1986, 29-31). These ports were determined by looking at four different aspects; where it is situated, the condition of the site, the overall layout and the structures needed at the harbor. The location would depend on the traffic that is going between the hinterland and the sea, most times the ports or harbors would be located near the mouth of rivers. The condition often limits building big harbors, for example if an area is more rocky, smaller ships would have to be used because of the limited ability to build structures in that area. This changed when the Romans started using hydraulic concrete or cement, which allowed them to build in the water. The layout and the structures of the harbors were determined by the environmental conditions. Types and sizes of ships, along with the wind and waves would determine the layout and how much protection was needed to accommodate it. This leads into the structures, also determined by the size and quantity. The structures built also depended on the materials that were available in the region (Marriner, 2007).

These ports have played important roles throughout history and were important to the everyday life of citizens in the Roman Empire. Some of these roles were travel and exploration. Ports opened up opportunities for people to connect with one another in different regions. They were also used for war, peace, exploitation and slavery. Romans and other ancient civilizations manipulated the environment and developed technology to be able to build these ports (Rogers 2013, 182). Most importantly, they were used for trade, which was essential in an empire that consumed over 650 million pounds of wheat annually. Due to the high consumption of grain, the Romans had to import it from other areas along with other items, such as olive oil, wine, *garum* (fish sauce), slaves and building materials (Urbanus, 2015). On top of this, ports allowed merchants to pursue their own profits with the infrastructure that is found throughout the port cities. Many merchants would set up stalls and shops in port cities to sell their goods (Rice 1996, 9-11).

## **Salt Works**

Salt works is the other sea installation that will be examined. Salt works were important to coastal towns because they would boost their economy through the process of taking salt from the sea and trade with the inland communities. These salt works were spread across the

Mediterranean Sea. Salt works were basins set up along the seashore at various levels so the drying process could be controlled (Walsh 2014, 61). These salt works were sometimes lined with rocks to separate each basin that was connected to a body of water (National, 2017). Salt can come from four different types of materials. These materials were rock salt, saline waters, saline soils and saline or even non-saline plants. The typical material that was used in Roman time was saline waters. The saline waters must be put through gradation to produce enough salt (Guoletquer 2015, 15-19). The ingredients to make salt out of the saline waters was the sea water, sun and wind. The flow of sea water was important to salt making. Unfortunately, due to changes in the environment, salt production became more difficult. (Lupi, 2018). Sea water would fill these basins and evaporate off when the sun got hot enough. As the water evaporated the salt would be left over. To get enough salt, the ratio of the brine had to be just right, if it was too diluted it would not produce enough salt (Pavlova et al. 1998, 357-358). This is why many salt works have terraced basins. Once the salt was visible and the water was evaporated off, the salt would be shoveled up and piled to allow it to dry (National, 2017).

Looking at prehistoric times, salt was collected from rocks and salt springs. The separation of salt started in the Neolithic Era. Evidence of the pre-historic production of salt can be seen with catchments or fittings made of wood, fired clay vessels, salt pan fragments, stone tools and other archaeological evidence. In ancient times, there is evidence of larger structures in lagoons. An example of this was found in the Maccarese lagoon South West of Rome. This specific lagoon changed from fresh water to brackish water. Brackish water is the combination of saltwater and fresh water. This change allowed for the construction of the salt works (Grossi et al. 2015, 91). Other ways to see the existence of salt works are by looking underwater at walls or barriers. Examples of this can be seen in Soline Bay where there is evidence of a salt works in the lagoon by a Roman villa. This salt work was probably been used for local production and not shipped out to other parts of the empire (Begović et al., 2012). Smaller salt works were often worked on at the local level. The salt produced by the smaller salt works was kept local or sold in the market. The maintenance and repair of these salt works would be under the direction of the owners of the maritime villas. Salt works at the maritime villas were often associated with fishponds to produce salted fish for consumption. Fishponds were also located at larger, wealthier estates, but the fish there was used for banquets and feasts instead of preservation. Larger salt works were often taken over by the imperial government to produce salt for the

empire. The first salt work that was providing for the Roman Empire was in Ostia. These saltworks were called *salinae romanae*, which can be translated to a state monopoly of salt. The government would put into place managers to oversee operations and repair, which were known as *salinatores* (Piplović, 2003).

Salt was important to the Roman Empire because it was used to preserve food, such as fish and other meats. It was used to be able to feed the armies of Rome through salted meat rations (Gerrard 2008, 117-122). Salt often stimulated military conflicts during the Roman Empire as well as other empires throughout time. The control of the salt works in the Tiber estuary was a reason for Rome's rise to power. Salt was considered white gold of the region. Salt was also used as flux in metallurgy. It was also used as a condiment for meals as well as livestock feed (Grossi et al. 2015, 86). On top of the feed for animals, herders would also aide in the transportation of salt from the coasts to the inland areas (Cuello et al. 2019, 164-168). Ancient sources often mentioned the use of salt to purify water and aide in the use of medicines. One medicine was a weariness solution called *acopa*. Other medicines included those that would help purge the bowels (Pliny NH, 31, 42).

## **Engineering**

Engineering can be defined as an “association with building design and construction from the time when people started to use large stones in preference to timber, mud bricks or small stones that could be lifted by one or two people” (Addis 2007, 13). The Romans knew how to engineer things that would last a long time. We can see this by just looking at major cities throughout the ancient Roman Empire. Even in Rome itself there are buildings that are still standing 2000 years later.

Engineering in the Roman Empire was taught mainly through apprenticeship, but also through the books of great Greek writers as well as books of their own. Many of the books that were written by Romans were lost (Addis 2007, 27). Based off the consistency between the engineering of harbors, it can be speculated that there were manuals on harbor engineering but had similar fates along with the other Roman engineering books (Blackman 2009, 641-642). Fortunately, there is one that is still intact by Roman engineer and architect, Vitruvius. In his book *De Architectura*, (more commonly spelt *Architectura*) he opens with “*Architectura* [engineering and architecture] is a body of knowledge comprising many disciplines and sciences

which can also be applied in other arts” (Addis 2007, 30). The knowledge that came through trade routes may have influenced Roman engineering in how things were built and designed. The trade allows them to see many different parts of the world. One example of this, the style of Greek architecture that can be seen in temples throughout Rome. The Romans enhanced and maintained higher levels of engineering technology than was previously achieved by the Greeks. They were able to learn the Greek style through educational infrastructure that was developed, specifically at the university in Alexandria (Addis 2007, 27).

### **Roman Engineers**

There were many engineers in the Roman world, unfortunately not a lot is known about them due to the loss of manuscripts and other public records from the Ancient Roman Empire. There was one engineer that we know about today named Vitruvius. We know about him because of his writing *De Architectura*, translated to *On Architecture*. It is believed that he wrote this work later in his life, potentially during retirement from military duty. His work was published in 25 BC and was dedicated to Augustus. He began his career acting as an engineer for the military where he built and repaired ballistae and catapults. He took charge of the civil engineering projects such as water supply that helped rebuild Rome. He served under both Julius Caesar and Augustus (Addis 2007, 28-31). There were other known architects during ancient times such as Apollodorus of Damascus, Celer, Severus, Decrianus, Hermodorus of Salamis, and Rabirius. All of these architects were under the service of the emperors, some served in the military at some point, like Vitruvius did (Claridge 2010, 522).

### **Legacy of Roman Engineering**

As said before, the Romans advanced their knowledge of how to engineer buildings and machines, from their teachers, the Greeks. An example of the advancement can be seen in the harbors and ports. The Greeks built their off-loading area with ashlar blocks and clamps and the breakwaters were rubble. The Romans had a structural concrete called hydraulic concrete, which would allow for building in the water instead of on land. This advancement allowed Romans to build their ports virtually anyway (Lancaster 2009, 261). Other advancements the Romans made to engineering was the ability to manufacture large quantities of artificial construction material, have precision in their measuring and surveying skills, the organization and training of workers,

being able to manage logistics to receive the supplies of materials that is needed and to manipulate stones of huge size and weight (Addis 2007, 34).

### **How architecture and construction work**

Vitruvius gave good insight to how architecture and construction worked in the Roman Empire. First, he split architecture in three ways. They were the construction of buildings, construction of machines and then the construction of sundials. Then, he split construction even further up by making two sections, one for city walls and civic buildings and the other is private buildings (Vitruvius 2014, 19). Both ports and salt works fall under the civic buildings because they were used by the cities and states. Salt works could be considered a private construction because most of the salt works were locally owned.

Ports and harbors had some specific criteria for the location to where they could be built. They had to be situated in relation to the sea currents and winds otherwise there would be more degradation in the port. Not every location will have the same currents nor the same winds. If ports were built to coincide with the currents and winds, then there would be a natural highway for ships (Walsh 2014, 65). Natural landscapes were an advantage for the harbors built there due to the natural protection from storms. Vitruvius gives many ways on how to build these harbors and ports. One of the many ways was to bind oak planks together with chains and sinking them to make moles and quays (Vitruvius 2014, 160-166). The foundations of many buildings in the port towns were often below sea level. *Piscinae*, or fishponds, were one of the infrastructures with the foundation located below sea level. Water channels were also built below sea level to increase the flow of water through the harbor, which aided in the prevention of silting. Other components of harbors that prevented silting were the breakwaters and moles. These were formed with rubble being dumped in the sea and then adding a wall or road on top of them. There is evidence that both the Phoenicians and the Romans used these methods. The Romans built more elaborate ones by using stone and concrete instead of just rubble. The Romans added arches to the moles, so the natural flow of the current was able to aid in the prevention of silting (Flemming 1969, 8-10).

Moles often had a large effect of the sand deposition. The coastline could have been different if the natural process of flow was not disrupted due to the building of harbors and moles (Walsh 2014, 61). Moles were used for protection, not just from the currents, but also from attacks by

the enemy. Therefore, it was important to have the construction right. It was simplest to line it up with the natural formations of the reef or rocks. It was important to have the outer faces of the moles be sloped so it would stabilize any materials that were used as well as prevent any wave action. Similar to how the arches worked in aiding the flow of water, some moles were designed to have water flow over the top of them (Blackman 2009, 645-651). Quays are the places where cargo was unloaded and were built up so that waves could not break over them. If the ships were lighter, they could be hauled onto slipways, which were used more by the Phoenicians and Greeks and not as much by the Romans. On a slipway, the lower end would be submerged underwater (Flemming 1969, 8-10).

To extend the inland reach of the ports, canals were often built to connect the harbor to a major body of water. A positive for these canals is that they allowed goods to go directly to the river or lake and avoid any further sea travel that could be dangerous. On the negative side, it affected the drainage of the rivers or lakes that the canals connected to, which both helped and hindered the environmental effects of the area (Wilson 2013, 270). An inscription records Emperor Claudius' intervention of the constructing canals to relieve the Tiber from flooding:

“Ti. Claudius Drusi f. Caesar ... fossis ductis a Tiberi operis portu caussa emissisque in mare urbem inundationis periculo liberavit”

“Tiberius Claudius Caesar, son of Drusus, ... freed the city from the danger of flooding by leading canals from the Tiber into the sea in connection with the building of the harbour” (Wilson 2013, 270-271).

In these canals there were locks and sluices gates that were used to as dry-docks and to extend the river routes that already existed. Due to the affect that the canals had on the bodies of water, much thought was put into the design and location of the canals. There are letters from Pliny the Younger to Emperor Trajan discussing connecting a lake with the sea and people wanting to help with the project in the province of Bythnia, in modern day Turkey. Emperor Trajan responding saying that there must be an accurate survey so that the water doesn't drain instantly when the canals are running to the sea. He also instructed Pliny: “You can apply to Calpurnius Macer for an engineer, and I will send you out someone who has experience of this sort of work” (Greene 1986, 34-35). This shows that there was imperial intervention and engagement in engineering projects in provinces.



Romans were able to advance their technology with the use of concrete, especially hydraulic concrete (Greene 1986, 28-31). To be able to help set the concrete and mortar, formworks were needed to aid in the building of the harbors and ports due to the sea's dynamic environment. The design of these formworks depended on what they were used for, the environment of where they would be used, the character of the concrete and if the cladding was temporary or permanent. Timber was often used as the cladding of the formwork. The organic nature of timber makes it difficult to see evidence of its use, but there are impressions of where the pieces of timber laid (Brandon 2014, 189-222). The use of hydraulic concrete in harbors was desirable for many reasons, whether it was political, military, and economic (Blackman 2009, 643-645).

### **Different Materials used in construction**

Many different materials are used in construction today and there was no difference in the amount of materials used in ancient times. One of the difference of construction today versus in ancient times is the type of materials that were used. Vitruvius discusses the multiple different types of stones that were used to construct buildings and walls. He also discusses different woods and what uses they had for construction. One of the most important materials for engineering in the Roman world was concrete. Concrete was made up of the combination of lime mortar and an aggregate. It was used as infill for structures that had load bearing materials such as stone and became a major building material by the 2<sup>nd</sup> century BC (Claridge 2010, 44). Aggregate could be used in two main forms. One type was a fine and sandy aggregate, which was available anywhere. Another was a coarse aggregate, which was found in quarries and made up of crushed rocks.

Concrete was first created with synthetic lime mortars and a mixture of slaked lime and quartz sand that dates back to 12,000 BC in the Near East. In about 10,000 BC these mixtures can be found in the application of architecture. It has been said that the Romans and other local builders in the area may not have known the exact properties to the volcanic ash when it was first implemented into concrete (Oelson 2014, 2-4). As discussed early, the Romans were able to create a concrete that would set underwater called hydraulic concrete. This concrete comprised of pozzolana and lime, both of which gave the concrete strength. Pozzolana also gave the concrete the ability to set under water. Pozzolana was volcanic sand that was found throughout central Italy (Lancaster 2009, 261-262). The lime mortar came from roasting limestone, which

was found in the Sabine hills near Rome, and gypsum, found in a lime kiln. The hydraulic concrete's ability to set underwater was not the only difference compared to its predecessor. The other difference is that hydraulic concrete was poured and not laid (Claridge 2010, 44). The hydraulic concrete was a significant development in ancient construction because it allowed for the construction of harbors in unbuildable areas. The hydraulic concrete was used for the building of moles that protected the offshore harbors, which was done multiple ways and on sandy beds a rubble cushion was used to support the mole. This concrete can be seen on a number of sites, some of them being Baiae near Naples and Portus Iulius, built by Augustus in the Bay of Naples (Walsh 2014, 56-61). The concrete is strong, which can be seen in the 2000-year-old structures that are still intact. These structures were built using four ingredients. The first is the volcanic ash, pozzolana. It came from pyroclastic deposits that were from volcanic eruptions. The second is the lime that comes from heated limestone. The third is sea water. The last is *caementa*, which often comes from volcanic eruptions but also can be from local rocks or ceramic fragments (Jackson 2014, 144-145). Roman concrete needed a large quantity of water, which made it almost impossible to use everywhere until the aqueducts were built, the first one by Appius in 312 BC. As time went on the Romans created a concrete that could be poured as well as set under water. A difference between the concrete of the ancient Romans and the modern-day concrete is the size of the stones that were used and the method that it was put into place. Modern concrete uses smaller stones and is poured so that it can set. Roman concrete used larger stone and the method was a wet technology that required the stones to be set into the mortar and tapped into place (Lancaster 2009, 261-262).

## **Ostia**

The ancient city of Rome was over 20 km inland, which meant there needed to be a connection somewhere for the Mediterranean trade networks. Rome relied on the Tiber River and the harbor that was located by the Capitoline Hill, but this was not enough since it could not handle a large number of ships and it was not deep enough (Urbanus 2015, 28-29). The solution was the founding of the port city of Ostia. Traditionally, Ancus Marcius, the fourth king of Rome founded Ostia in the 7<sup>th</sup> century BC (Huijzendveld, 2020b). Even though stories tell of the finding linked to the fourth king of Rome, the urban center of Ostia was not established until the 4<sup>th</sup> century BC in the form of the Castrum, or fortress (Goiran et al., 2017). The word Ostia

comes from the Latin word *ostium*, or river mouth, and is located on the River Tiber. It is 20 kilometers away from Rome and was linked to the growth of the city. There were multiple reasons for the foundation of Ostia. One was for the management of the salt works located in the lagoons. It was also used for the establishment of the fluvio-maritime port downstream of Rome. Finally, it was also to control the access to the Tyrrhenian Sea from the Tiber (Salomon et al., 2018). It is unknown completely if these were the only reasons because there is a lack of written records due that time frame. When it first was founded, it was only an outpost because of the coastal barrier being too narrow. This barrier is what separated the sea from the marsh. (Huijzendveld, 2020b). There is a historical account written by Titus Livius, also known as Livy, about the city and port. In Livy's 33<sup>rd</sup> chapter of his first book, he talks about the establishment of Ostia after the Maesian Forest was taken away from the Veientians what extended the dominion of the Romans to the sea. Also, in this section of his writings he talks about the salt pits that were nearby. Later, in chapter 9 of his second book, he recalls the Senate taking the salt sales out of the hands of the people and putting it under government control (Livy HR, 2, 9). The salt works of Ostia, Stagno Ostiensis, have not been located but there are possible warehouses and wharfs in a suburban zone. There is evidence of the salt works in the Casalone, a medieval building. Based off of various photos and drawings, the salt works were suspected to be in serial basins. Brine would collect in the shallow basins and evaporated in the sun. The low tidal range was only 30-40 cm so the high tide would bring the sea water into the basins (Huijzendveld, 2020b). During the First Punic War in 267 BC, Ostia was used as a naval station. At the same time, it was also used as a commercial port, providing olive oil from Spain and grain from North Africa (Delile et al., 2018). The supply of food continued and grew in the mid and late Republican period. The construction of a warehouse was linked to the 1<sup>st</sup> century BC. The walls of the city were built in 63-58 BC. The entire city covers over 70 hectares. By the 2<sup>nd</sup> century AD, construction in the city slowed and during late antiquity the city started to be abandoned. The decline of Ostia can be directly linked to the decline of Rome. The demands of food declined due to natural hazards (Salomon et al., 2018).

Julius Caesar thought about building a harbor at Ostia as well as wanting to construct a canal that connected Terracina to Rome. During Nero's reign, there was a connection made from Ostia to Rome. This connection was made through Lake Avernus. Emperor Claudius added a cohort to Ostia so that there was a fire service there (Rice 1996, 9-11). There was a port in Naples, called

Puteoli, but there was a large distance between Puteoli and Ostia. This distance added to the need to build Portus near Ostia (Delile et al., 2018). Ostia was the key port city in the harbor system of Rome. Portus helped commercial activity due to the natural constraints of Ostia (Salomon et al., 2018).

Ostia was affected by silting from the deposit of sediments due to the southerly winds and currents. This silting caused the eventual closure of the harbor (Walsh 2014, 58). The Tiber Delta was the outlet for any sediment and water that was collected along the 405-kilometer river. The watershed has a surface area of 17,375 square kilometers. This meant that the river would deposit approximately 7.2 million tons of sediment into the Tyrrhenian Sea each year. Using this information, the Tiber delta had a seaward progression that cause difficulty knowing the dynamics of the coastline during Roman times, which in turn made it difficult to find evidence this port city. There is evidence that during the time period between 230 and 450 AD, the sea level was around 0.8 meters below the current level today. Stratigraphy also shows that silt has deposits of depths of 5.7 meters and 9 meters below ground level, which is 2.5 to 5.8 meters below the ancient sea level (Delile et al., 2018). The silting was also affecting the large port located north of Ostia, called Portus.

## **Portus**

During the reign of Emperor Claudius, which started in AD 41 and ended AD 54, the harbor of Portus was built. The construction was started in AD 42 and the port was functioning in AD 46. The city and port were not fully finished until the reign of Nero, who dedicated it in AD 64. It is located 4 kilometers north of the Tiber's mouth and in turn north of Ostia. This port was meant to help Ostia keep up with the higher demands of food and it was to replace Puteoli in the Gulf of Naples (Hohlfelder 2014, 55-102). In Cassius Dio's 60<sup>th</sup> book of his recorded histories, he mentions that all of the grain for Rome was imported and there was a need for a safer landing space or port. For this reason, Claudius took on the building of the harbor (Cass. RH, 60). This port was originally the dream of Julius Caesar's but was unable to be completed because of the lack of engineering knowledge at the time. The knowledge that was previously lacking grew during the time leading up to Claudius' rule. The port was an architectural and engineering showpiece. The force of the sea made it difficult to design the port, but with the technology of hydraulic concrete it was able to have the infrastructure built in the sea. Another difficulty for

this port is that it was also dealing with the flooding and silting of the Tiber. To add to this, it was situated on a marsh. Cassius Dio recorded in his histories, that the engineers that were consulted for this project were nervous to provide the cost of the port. This project was important to Claudius because he needed a way to confirm his legitimacy to be the ruler after Caligula was assassinated. It also gave Claudius the position as a patron of the Romans because of the local significance that came with the employment and grain imports. Another reason for becoming the patron was the works he did to help mitigate the flooding of the Tiber (Hohlfelder 2014, 55-102). Cassius Dio also recorded in Book 60 of his histories, that Claudius first excavated the land and built retaining walls on all sides before opening up the basin to the sea. He continued to construct moles on both sides of the entrances to enclose the large body of water (Cass. RH, 60).

The basin of the Portus' first harbor became to be known as the Claudian Basin after the addition by Trajan. The Claudian Basin was 200 hectares in size, which was as large as the harbor in Alexandria and three times the size of Puteoli. It faced west with a lighthouse island whose foundation was a freighter that was sunk with hydraulic concrete (Hohlfelder 2014, 55-102). The building of this port in the Tiber Valley was also used to build relief canals for the Tiber (Wilson 2013, 270). Two canals were connecting the river, the sea and settlement on Isola Sacra (Keay 2010, 18-19). These canals were 90 meters wide and were 3 km long. The depth of the Claudian Basin was 6 meters and allowed for ships to carry 500 tons of cargo (Urbanus 2015, 30-33). The canals allowed the movement of cargo to Rome on river boats after being unloaded in the port. Part of the relief that these canals had on Rome was the prevention of floods (Mladenović et al., 2019).

Emperor Trajan, as recorded by Cassius Dio in his 68<sup>th</sup> book, tended to spend money obtained by war on works of peace. One of these works of peace was the expansion of Portus. The money that was typically used to build the harbor and other public buildings was not from warring and killing but rather a method that received government funds from taxing the ports and people in the empire (Cass. RH, 68). During Emperor Trajan's rule in the 2<sup>nd</sup> century AD, a large hexagonal basin was added inland to the Claudian Basin. Trajan also added more canals that connected the port facilities to the Tiber River. Coins were commemorating once it was finished, bearing Portus Traiani on the face (Hohlfelder 2014, 55-102). The new basin and buildings were built between 110-117 AD. The new buildings included a temple, precinct, the Palazzo Imperiale and other administration buildings. There is also archaeological evidence that there may have

been a shipbuilding area and warehouse on the site. Trajan also rebuilt areas that were started by Claudius and Nero (Mladenović, 2019). This hexagonal basin was 32 hectares and increased the docking capabilities. The new complex covers 3.5 square kilometers. The Palazzo Imperiale was completed in AD 117 and was located between the new and old basins (Keau 2010, 19-20). The redevelopment of Portus by Trajan was to show a sign of power and glory. An example of the power and glory of the emperor and of Rome could have been seen in the form of a statue of Trajan upon entering the new basin (Urbanus 2015, 30-33). Construction continued on past the reigns of Claudius and Trajan. The construction was in the form of new buildings and walls as well as alterations to existing buildings. During late antiquity Christian churches were established there and commercial pursuits began to dwindle. The Claudian Basin was largely silted up by 6<sup>th</sup> century AD and the buildings were altogether abandoned or demolished during the Gothic Wars between the Byzantines and Ostrogoths in AD 535 to AD 553 (Mladenović et al., 2019).

Portus was built with a purpose to make the Tiber mouth safer for the additional ships. It was also used to attempt to centralize the commerce of Rome, specifically the importing of grain. There was an increase of granaries and storehouse and there was the ability to anchor more than 600 ships at Portus. Making the ability to unload and bring grain into Rome easier and faster (Rice 1996, 9-11). The harbors were built due to economic reasons, the need to bring in more goods, and for environmental reasons, having a deep-water port that can be connected to the river. Immediately after the construction of Trajan's Basin it began to succumb to silting, which caused the abandonment and disuse by the end of the 5<sup>th</sup> century AD (Walsh 2014, 60-61).

## **Soline**

The Roman Villa that is located near Soline Cove on the Island of St. Clement has been excavated since 2007. The first archaeological investigations started 50 years prior. Many different methods were used to examine the villa and surrounding area. One of these methods was a geodetic survey, which allowed a scale rendering of the villa to be made. There were also electromagnetic surveys carried out throughout the site. In 2010, the island itself was mapped out using GPS. Through the mapping it was discovered that there were paths, fields, stone quarries and limekilns as well as various archaeological sites on the island. The island of St. Clement is 5.3 square kilometer and the largest of the Pakleni archipelago. Soline Cove, located on the south

side of the island, has the best natural protection and has been important to the waters surrounding the island. Soline cove allowed boats to land in most weather conditions, except in the case of strong southern winds. There was a cove on the north side of the island that allowed boats to land when there were strong southern winds. There are little ports in both coves that were used in ancient times as well as today. The Roman villa that is excavated is one of 30 that are located on the eastern Adriatic coast.

Wells that were used for drinking water have been found in caves. The water in the wells are now brackish due to the rising sea level, which have risen 2 meters since ancient times. There was a limestone quarry found and it can be linked with what Pliny the Elder wrote in his book, *Natural History*, about marble limestone located in the region. This cove is important in a historical context because of the fertile land around it and the ancient maritime trade routes. The archaeologists working on the site claim, "Soline would have been a suitable port for provisions of food and water, as well as shelter in case of a storm" (Begović et al. 2012, 148). It has been speculated that this site also could have been used to control naval routes because of the ability to oversee the routes at the Glavica Peak, 80 meters above sea level (Begović et al. 2012, 144-148).

The maritime villa located at Soline Cove is next to the fertile plain. The remains are located on the shore of the eastern part of the cove. The location would have had the advantage of a calm sea and the ability to develop architecture along the shores. Some of the findings on the site are stone remains that may have been a pier. There were also remains of mosaics in the buildings throughout the villa. A member of the first archaeological investigations, M. Zaninović, wrote about small salt works and fishponds that belonged to Roman villas in the Adriatic region (Begović et al. 2012, 149-154).

The name Soline indicates that salt works were located at this cove. There were remains of partition walls in shallow waters at the end of the cove. There are documents from medieval times that mention that salt works are located there. With the information in historical documents and previous findings, the investigators were able to use aerial imagery to see remains of four walls located underwater. These walls span the breadth of the cove. They are suspected to be the walls of the salt works. It is difficult to examine and take measurements of these walls due to silt that has been deposited in the cove. The size of the salt works indicated that they produced enough salt for those who were living at the villa as well as to sell at a market. The salt works

were important to the economy of the island, which can be seen that they were still in production beyond the Roman period (Begović et al. 2012, 155-156).

Findings in 2016 show production spaces located north and east of the main building. A round stone structure was also found and was thought to be the base of a press for olive oil or wine. Also, it is thought that some of the residential areas were repurposed for agricultural production. These findings indicate that there was a strategic role this villa played in the trading in the Mediterranean. It also had an economic and a navigational role (Ugarković et al. 2017). The following year, the production areas of the villa were examined further. During the examination, waterproof mortar in two basins was discovered. There was a small and deep basin as well as two larger and shallower basins. These basins could be linked to an early phase of the villa and could have been used for the production of fine salt. This along with the evidence of the architectural changes through the years shows that it was a successful and important estate for the role in the Mediterranean networks (Ugarković et al. 2018). With further excavations done on the two basins in 2018, there were findings that the basins had two layers of waterproof mortar. The probes also showed that they were connected both spatially and functionally with the production installations that have been uncovered in previous years (Ugarković et al. 2019).

### **Environmental Changes**

The changes to sea level can happen because of the sedimentary deposition or through the changes in climate. These changes did not only impact the coastal societies, but it also affected those in the hinterlands because erosion would make its way inland. The hinterland would also be affected through the challenges the trade networks would face on the coast (Walsh 2014, 64-65). One of the major changes that happened was with the Tiber River. The changes of the river greatly affected Rome because of how interconnected the development of the city is with the river. The flooding that took place in Rome was often due to the erosion of the Tiber which in the central Apennines, which affected the entirety of the river (Walsh 2014, 96-97).

To be able to see what lay beneath the topsoil and how extensive the environmental changes were, archaeologists and other specialists use geophysical surveys. This would include coring, which was taking a sample of the different layers in the soil. The technique of coring was used at Portus, as well as other ancient ports that were being researched. The soil samples brought new information in about the effects of the environmental changes that were going on (Mladenović et



al., 2019). Micro-XRF scanners is a non-destructive way to examine the sediment cores that were taken at various sites. This test produces profiles of the elements that made up the material. There are three main materials that are looked for. Detrital material, which is the continental crust and volcanic rocks. This material can be carried by water to a marine watershed. Authigenic material looks at the organic and inorganic interactions and is dependent on the ventilation conditions of the bottom of the water. The third material is biogenic. This is produced by photosynthesis of organic material. It shows skeletal remains and it depends on the concentration and supply of nutrients of the surface waters (Delile et al., 2018).

A good portion of the knowledge about the environmental effects on ports come from the research expeditions that were done on a port located in Israel. This port is Caesarea, built by King Herod around 22 BC and finished in 15 BC. Caesarea was a large deep-sea harbor with many storerooms, markets, roads and other infrastructure that allowed goods to move across the Mediterranean. Archaeologists were able to see the concrete structures due to the Roman Maritime Concrete Study, also known as ROMACONS. This study showed how hydraulic concrete was set to build the ports. Being able to see how things were built allowed for more study to be done on how they were maintained (Roman, 2019). Ostia is another example of the examination of sediment that filled ancient harbors. The basin of Ostia was difficult to find without using geophysical methods, like coring. The cores showed the different layers of sediment that was linked to different eras in the Roman Republic and eventually the Roman Empire. These cores also showed the attempts to reduce the amount of flooding that happened on the Tiber by seeing accumulation of certain materials (Goiran et al, 2017).

## **Climate Changes**

During the maximum expansion of Rome from 100 BC to 150 AD, there was a stable climate, which started to become unstable after 150 AD. During this time, glaciers began to grow again and there were more frequent volcanic eruptions. To add to this in the 3<sup>rd</sup> century AD the amount of precipitation declined for the spring and summer. It wasn't until the end of the 4<sup>th</sup> Century when things began to get wetter and warmer. These impacts caused large negative impacts within Rome. The draughts would negatively impact the amount of food that was produced in the provinces of Rome. The instability returned between AD 400 and AD 600, which brought more drought and height events, volcanic activity and even solar radiation to the

declining Empire (McCormick 2013, 70-72). With these changes to the climate brought different types of change. There is the short-term rapid change that is connected with the effects of the volcanic eruptions. The other is the long-term environmental shift, which often changes the growing seasons and often times generate human responses that are successful. With these changes, the transportation sector of Rome was capable of addressing the famines (McCormick 2013, 82).

These climate changes could have led to the change in the sea levels. Looking at the level of the sea over time, the position is determined by the marine water level and the quantity of the sediment that is transported from the rivers to the sea. During prehistoric times, the sea rose 125 meters to a stable level that isn't much different today. There was an inland movement of the coasts and later the coasts were governed mainly by sediment. The amount of sediment depends on the river, force of waves in the sea as well as the marine currents' strength and direction. These factors can cause an increase or decrease of the coastline (Huijzendveld, 2020a). Over the last 2,000 years the level of the sea was settling from around 1.5 m to at least 0.63 mm a year. The sea wasn't linear, and it wasn't stable. For the Roman sea level, it was about 50 cm of change (Walsh 2014, 52). The most vulnerable settlements that require a constant and rapid human response are those that are adjacent to the sea. The response must be either the abandonment of the settlement or a modification of the environment around the settlement. The marine transgression and retreat of the shoreline has been well documented since 9000 BP. Human history has been filled with milestones that force the climate, making the changes to the natural environment around them so that the humans can continue to live there, an example of this at Atlit-Yam, in Israel. The well had stones at the bottom so the water level would rise to avoid the salinization from the sea (Galili et al., 2019).

The sea wasn't the only body of water that was affected by the climate and sediment. Today the Tiber is flowing differently than it was 2000 years ago. The migration of the Tiber happened in several phases. These phases were recorded by the different positions of the delta cusp. The first phase lasted from 3,000 BC to the 7<sup>th</sup> Century BC. The second phase is when the Tiber migrated south through the Stagno Ostiensis and breaking the dune belt near the future city of Ostia. The third phase is linked to when Emperor Trajan created the channel that connected Portus to the river. This created progradation of the delta making two river branches active at the same time. The frequent flooding of the Tiber started happening. The flooding was occurring

around 30 times a year (Huijzendveld, 2020a). Pliny the Younger described some of the flooding that was occurring. He described the flood that happened during Trajan's reign as not being contained by the spillway that was built by Trajan. The river was the soul of Rome and when it flooded it flooded the city (Harper 2017, 47).

### **Tectonic movements**

Another possible reasons behind the change in sea level could be because of tectonic movements. There has been some evidence to show that sudden movements could change the sea level had an immediate impact on the coastal activities in the area. In the areas that are affected by tectonic changes would have different responses compared to those who have the gradual changes of the sea level. Tectonic activity can lead to an exaggerated rise in the relative sea level caused by the land moving downwards or an exaggerated fall in sea level when the land moves upward (Walsh 2014, 35-37). In Caesarea, breakwaters were tilted and started to settle into the seabed due to the seismic activity. There was also archaeological evidence of a tsunami that struck the area during either the 1<sup>st</sup> Century or 2<sup>nd</sup> Century AD (Roman, 2019). The amount of water that is moved due to the tectonic activity can be explained by the fact that hulls of ships were seen to touch the bottom of seas and harbors during the large earthquakes in the area (Bennett et al., 2008). Very little can be done to rebuild or prevent the effects of tectonic movements. Some of the rebuilding that can be seen is the slipways being raised in Rhodes, Greece. Central Mediterranean was considered geologically unstable, lined with many plate tectonics. The uplift of the land due to tectonics may have been a cause to abandonment as well as the submergence of the shoreline (Blackman 2009, 661-662).

### **Silting**

Silting was a large problem for harbors and ports. The harbor engineers would often run into siltation when building them. This happened especially near the mouths of rivers, which is an ideal spot for harbors of cities located in the hinterland. Often silting was caused by the dumping of refuse from stone working into the basin of the harbor. The depth of water must be maintained to allow for the ships of the Mediterranean to offload their goods. If there was a small tide range, the basin would not be flushed enough to combat the dumping of the refuse (Blackman 2006, 661). The infilling of harbors was a fundamental problem to handle and when ports were near a river delta, they would have the long shore action of the Mediterranean to combat. Shoreline

progradation has also been affected by volcanic eruptions due to the large input of sediment (Walsh 2014, 35-47).

## **Roman Responses**

Silting was one of the largest problems the Roman world faced for their harbors and ports. Dredging was used to combat silting and there is evidence of it being used in various locations. Archaeologists can find evidence of dredging in three different ways. It can be seen through the fossilized taluses, chronological inversions and chronostratigraphic gaps. The reason why dredging was happening was because the preventative measure that were used only slowed the silting problem by eventually dredging must occur to fix the depth of the harbors (Morhange, 2010). Dredging channels have been found in Naples dating to the end of the 4<sup>th</sup> century BC. Evidence for deep dredging has also been found in Marseilles that date to the 1<sup>st</sup>, 3<sup>rd</sup> and 4<sup>th</sup> centuries AD. Ships called dredgers have been found abandoned on beaches or reused in the foundations of quays. With all of this evidence, it shows that in antiquity, dredging was used to handle the silting issue as it was collecting (Blackman 2009, 661).

The Romans also had measures to prevent the silting of their harbors. Breakwaters were used to deflect any silt-bearing currents as well as to control the currents through the basins. There were also building desilting channels and tunnels. The tunnels were found in the moles to allow the current to flow in and out, flushing the basin in the process. The desilting channels brought silt free water into the harbor to help flush the silt out. Often, these measures made the matter worse by blocking the natural currents, especially in offshore breakwaters that are not connected to the land (Blackman 2009, 661). Silting was not only affecting the ports of Ostia and Portus but also all the harbors across the Mediterranean. Extensive dredging needed to take place in many harbors because of the seriousness of the problem. Harbors accumulate 10 to 20 times more silt than the natural coast (Walsh 2014, 55-56).

The ports in the Roman world were not the only locations to be affected. The Tiber River, among other bodies of water, were also being affected by the silt and environmental change. When building and extending Portus, Emperors Claudius and Trajan both created channels to relieve the Tiber in hopes that it would reduce the amount of flooding that was taking place. There have been inscriptions that explained that both emperors helped in the decrease of the Tiber flooding. These canals and channels sometimes did not work, and further measures were

limited to the repairing of the banks and dredging the channels (Wilson 2013, 270-271). The natural processes had different consequences for everyone. Many times, it would influence the structure of everyday life. There has been more emphasis on studying the ports and harbors in connections to the economic opportunities. The equal amount of emphasis should also be placed on the technological engagements of the environment (Walsh 2014, 64).

Salt works were also dealing with the environmental changes in the form of the rise in sea level. The way that the Romans combated the rising sea level at the salt works is not fully known because many of the salt works were being used through the medieval era. The evidence that can be seen are from the repairs and maintenance done during the medieval era and not from antiquity. There have been a few discoveries that could be linked to ancient method of maintenance. Some of these methods include the building of dams and dikes to keep the water out of the salt works. The dams and dikes often fell into disrepair and needed constant upkeep, which was expensive. The steps that were taken in more modern times for salt works were more plentiful than the steps taken during ancient times. One step was building ditches to keep the water from flooding into the basins. To add to this, new barrier walls would be built to keep the high tide out which was important to the concentration of the salt to water ratio. Unfortunately, the abandonment of many salt works was due to the inability to keep up funding for the constant repairs of the barriers (Piplović, 2003).

## **Modern Responses**

The modern approaches to the rising sea level and silting are like those the Romans used in ancient times. Dredging is one of the practices that has been used continuously to remove sediment. Today, dredging is used for the removal of sediment from the bottoms of lakes, rivers, harbors and any other bodies of water. The focus of the dredging is on the depth of the body of water. Dredging works to maintain or increase the depth of the navigation channels, anchorages and berthing areas. It is also used to reduce the exposure of wildlife and people to contaminants that could be in the water from dumping or other disasters. This kind of dredging is called environmental dredging (National, 2020).

Dealing with the rising sea level, specialists have placed the way people adapt in modern times into three different categories. These categories are to defend, accommodate and retreat. The category of defend would include building seawalls and barriers. This happens when there

are economic and engineering limitations. Accommodating would be building extra stormwater and flooding infrastructure as well as building green infrastructure to absorb or store large volumes of water. The category of retreat is the last option people want to take as well as an option that many communities cannot take (Russel, 2017).

Some steps that engineers and communities have taken are avoiding overbuilding of an area. This is to move away from the traditional engineering solutions especially when communities do not have the money to build defensive infrastructure. They also look at adaptive designs, which look towards the uncertainty of climate change and the rising sea level. It will help build infrastructure to be built now and change in the future. Buildings are being built with keeping only 10 years in mind whereas the past, the design would be for lasting 60 years. There are also new standards being put in place to focus on the rise in water, use of energy, windstorms and storm intensities. There are also structures being built to accommodate the water. One of the largest limiting factors to these steps is money. The federal government does not help in some situations and the future of the federal funding is uncertain. These steps combat the rising sea level in modern times and with time, they will change due to the uncertainty that is the climate and the sea (Russel, 2017).

## **Conclusion**

The upkeep of both salt works and ports depended on the location. Many salt works that have been discovered were local salt works and depended on the financial stability of the owners to keep up with the maintenance. Ports on the other hand were under the control of the government and the empire was in control of the maintenance and upkeep. To be able to maintain a working facility, both installations had to deal with the sea level. Therefore, they had to pay for building walls or dams to keep water out or pay for dredging to keep sediment out. These methods have been very similar to the methods that are used today to keep water out and to reduce the amount of sediment in the bodies of water. The Romans also had to be financially responsible for the upkeep of these installations and many times, it was too expensive to maintain them. People and governments today are facing similar financial problems to maintain their communities.

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