EUROPEAN SEAGRASSES: AN ASSESMENT OF THE CURRENT TRENDS

(Borum et al. 2013)

Bachelor thesis by Joost van der Laan
S2730405
Supervised by:
prof. dr. B.D.H.K. Eriksson
and L. Irazabal Gonzalez

Table of contents

Abstract
Seagrass meadows are ecosystems with a high productivity and biomass, which provide important ecosystem services; providing carbon for other marine ecosystems and purifying water. They are important to humans too, being a nursery for commercial fish species and protecting the coasts. The four seagrass species of Europe are highlighted in this review. They have been declining in the 20th century because of several causes: water quality degradation, wasting disease, coastal degradation and mechanical damage. All of these causes affected different species and measures to these threats have been taken to stop the decline, but outcomes vary: measures like the nutrient load reduction in runoff water have proven useful to alleviate water quality degradation, whereas anchoring restrictions failed to cease the threat of mechanical damage. We conclude that seagrass meadows in Europe are increasing again, and to ensure continuation of this increase measures need to be monitored and updated. Positivity is warranted, but letting go too soon could mean a trend shift once again.

1. Introduction

Seagrasses are adapted to be completely marine angiosperms by having; leaves with sheaves, hydrophilous pollination and lacunar systems (Hemminga & Duarte 2000, Kaiser et al. 2011). Seagrass meadows occur at both temperate and tropical coasts on every continent except Antarctica. They mostly grow in shallow waters, but if waters are clear enough for light to penetrate, they can grow down to 60 meters (Borum et al. 2004). Meadows in temperate regions are often monospecific, and in tropical waters they can contain up to twelve different species (Duarte 2001). There exist about fifty species of seagrasses worldwide, four of which occur in Europe: *Posidonia oceanica, Zostera marina*, *Zostera noltei* and *Cymodocea nodosa* (Santos et al. 2019).

Seagrass meadows are highly productive areas and provide food and shelter for a wide array of organisms. Turtles and sirenians graze on the seagrass and seahorses live and prey in the meadows, making them important conservation habitats (Kaiser et al. 2011). The whole plants provide a habitat and refuge to small invertebrates (Conolly 1997, Jackson et al. 2001, Lee et al. 2001), and the meadows serve as nursery grounds (Jackson et al. 2001).

Seagrass meadows are important to other marine ecosystems, such as salt marshes and estuaries. They are also important to humans, because they provide ecological services (Green & Short 2003) such as: acting as the nursery grounds for commercially important fish, being a carbon source, purifying the water and protecting the coast. Several species of drums and the barred sand bass (*Paralabrax nebulifer*) spend the first part of their life in seagrass meadows (Jackson et al. 2001). Seagrass meadows, therefore, are an important source of food and work for humankind. Seagrass meadows have a higher biomass and productivity than macro algae and phytoplankton - other major primary producers (Duarte & Chiscano 1999)-, thus, provide other marine ecosystems with carbon to sustain food webs. Water purification (Green & Short 2003) occurs due to sedimentary processes and uptake of nutrients by seagrass meadows. They can remove and trap nutrients from the surrounding water for a longer time than most ecosystems dominated by algae and/or plankton, alleviating eutrophication and pollution. Even though they do not directly help in the protection of the coast, by breaking and redirecting energy offshore, they do indirectly protect the coast by stabilizing and preserving the sediment in shallow waters (Ondiviela et al. 2014). While their impact in the global oceans might be relatively low, their influence on marine ecosystems and anthropological activities is immense (Green & Short 2003).

The problem in Europe is that during the 20th century, and at the start of the 21st century, most seagrass fields in Europe were declining because of four factors: water quality degradation, wasting disease, coastal modification and mechanical damage (Short & Wyllie-Echeverria 1996, Santos et al. 2019). Water quality degradation mainly affected *P. oceanica* and *Z. noltei*, while *Z. marina* decline was mainly attributed to a disease and *C. nodosa* was greatly affected by coastal modifications. The management of seagrass meadows caused tentative increases in seagrass plants in the 1990s and 2000s. One of such actions was the improvement of water quality, by reducing the industrial sewage into the sea. Prohibitions were also put in place to decrease the damage caused by boats, by anchorage for example. Natural colonization was the other major cause for increase in some cases during these years, such as recovery after disease and floods.

Duarte (2002) predicted a continuation of the decline in seagrass ecosystems that had been happening in the 20th century. Even though he was more positive about the developed world and their ability to stop the decline of seagrass meadows, things were not looking good around the turn of the century. Human activity was considered a big threat in the 20th century, and would likely continue to be the leading threat in the 21st century. Santos et al. (2019) concluded that seagrass meadows were indeed declining in the 20th century, but that there were definite signs that seagrass meadows were improving in Europe since the 1990s. In my opinion there has been a turnaround in the trends around seagrass, switching from declining to a moderate increase, but there is still a lot of management measurements that can be improved and caution to be taken. This review will look further into the question if seagrass fields in Europe are still in decline like they were in the 20th century, or if they are flourishing again due to taken measures.

2. European seagrasses

The four aforementioned European species of seagrass each occur under their own specific range and environmental variables. *C. nodosa* has an affinity for warm water and low tolerance to differences in salinity (Fernández-Torquemada & Sánchez-Lizano 2011). Thus, it is only found throughout the Mediterranean from the southern coasts of Portugal to Greece. It inhabits both shallow and deeper waters (50 to 60 meters), just as *P. oceanica*. *P. oceanica* reaches as far as the border where water from the Atlantic and the Mediterranean mixes below Spain (see figure 1). It only grows in very clear waters and is vulnerable to increases in salinity, only able to tolerate salinity slightly higher than the average salinity measured in the seawater (Sánchez-Lizaso et al. 2008). Both *Zostera* species are also found in the Mediterranean, but are more abundant in North European waters. *Z. marina* has the greatest range of all the European species, reaching from Northern Norway and Iceland all the way around Europe to Greece. The highest numbers of *Z. marina* are found in the northern seas; the Baltic sea, North Sea and along the Atlantic shores from France to Northern Spain (figure 1). *Z. marina* can survive in a wide range of salinities and temperatures, being able to survive a much higher salinity than is average in seawater and live in waters warmer than 30 degrees Celsius (Biebl & McRoy 1979). The most common ecotype of this species is found as a subtidal ecotype, it can also be found as an intertidal ecotype. The subtidal ecotype can be found until fifteen meters deep, depending on the water transparency. *Z. noltei* is mostly intertidal (table 1) and reaches as far north as the southern coasts of Sweden and Norway (Borum et al. 2004). *Z. noltei* is able to live in brackish waters, close to estuaries for example, while it is vulnerable to higher salinity levels that may occur during drought (Fernández-Torquemada & Sánchez-Lizano 2011). Water quality degradation mainly affected *P. oceanica* and *Z. noltei*, while *Z. marina* decline was mainly attributed to wasting disease and *C. nodosa* was mainly affected by coastal modifications.

Species:	*C. nodosa*	*P. oceanica*	*Z. marina*	*Z. noltei*
Depth:	Max. 60 meters	Max. 60 meters	Max 15 meters	Mostly intertidal (~0 meters)
Turbidity:	Turbid waters	Clear waters	Clear waters	-
Water temperature:	Mediterranean	Mediterranean	Polar till tropical, but mostly in temperate	Mostly temperate, but also Mediterranean
Salinity:	Vulnerable to lower and higher salinity	Vulnerable to lower and higher salinity	Tolerates very high salinity	Can live in brackish waters, vulnerable to higher salinity

Table 1: environmental variables under which the four European seagrass species occur*. Each species of seagrass has their limits of depth, turbidity, water temperature and salinity, thus each species exists under different condition.*

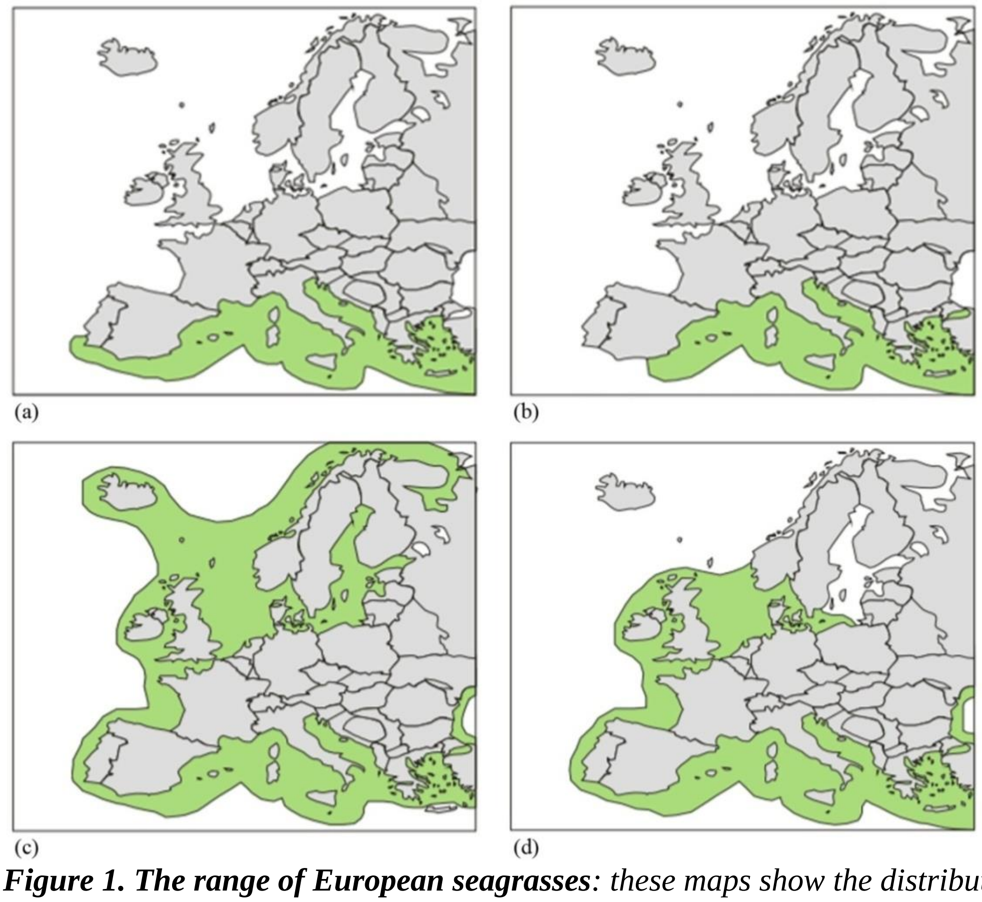

Figure 1. The range of European seagrasses*: these maps show the distribution of the four species of seagrass in Europe; (a) Cymodocea nodosa, (b) Posidonia oceanica, (c) Zostera marina and (d) Zostera noltei (Borum et al. 2004).*

3. Causes and measures

To answer the question if the measures against the causes are working, we looked at the causes and how they have affected seagrass meadows in the past. We will discuss how water quality degradation, wasting disease, coastal degradation and mechanical damage affect the seagrasses and which species they affect. The four species occur under different environmental variables (see table 1), thus they are vulnerable to different decline causes. The management measures will also be discussed together with the cause they were implemented for. Effective management (together with natural colonization) was the leading cause for the increase of seagrass and therefore measures will be judged on their effectiveness, ultimately seeing how much, they affected turnaround of seagrass meadows.

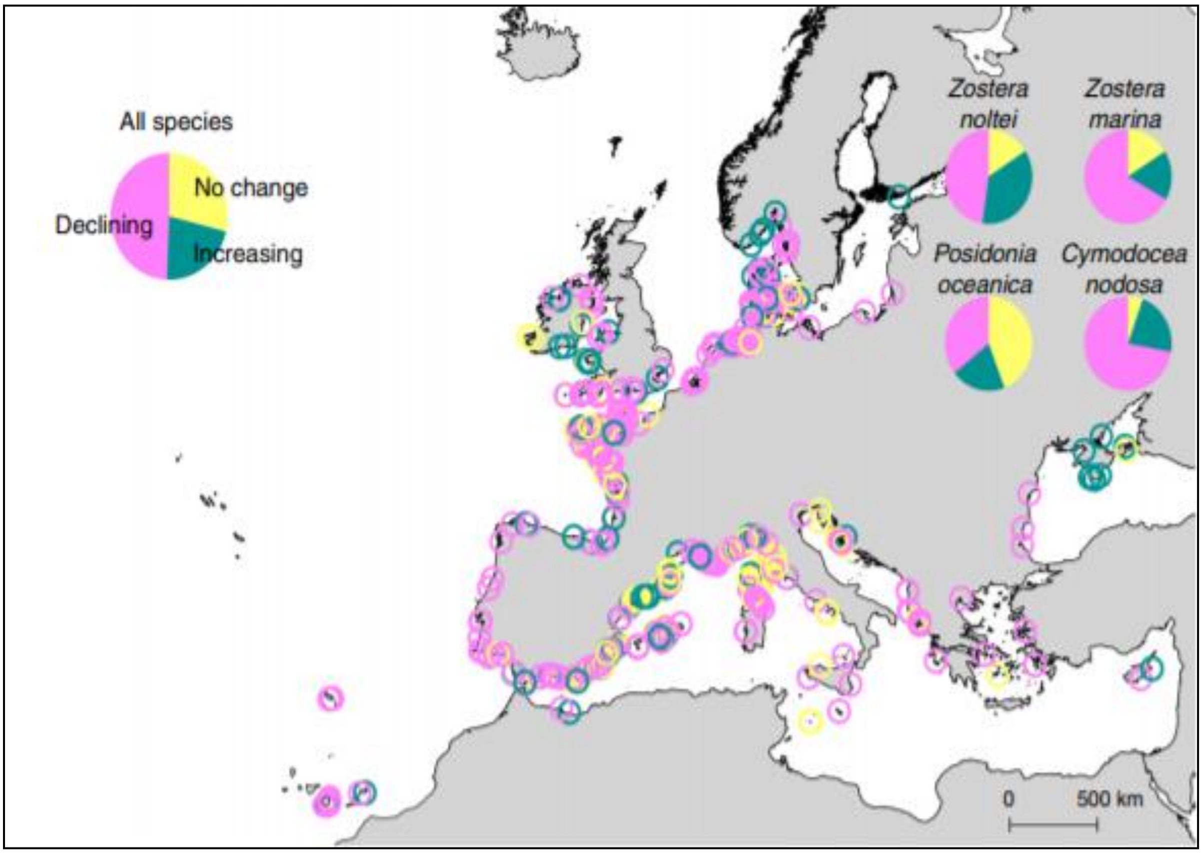

Figure 2: Overall trends of seagrass meadows from 1869 to 2016*. Decline is the leading trend for around half of the meadows, with Z. marina and C. nodosa declining the most. (Santos et al. 2019).*

3.1 Water quality degradation

The main reason this is a leading cause for seagrass decline is eutrophication (Short & Wyllie-Echeverria 1996). Most of these studies concerning water quality degradation have been done in *Z. marina* and in the Northern seas (Jansson & Dahlberg 1999, Baden et al. 2003, Dolch et al. 2013, Riemann et al. 2016, van Beusekom et al. 2019).

The Wadden Sea (ranging from the Netherlands to Western Denmark) has been impacted by eutrophication since the 1950s. In recent years the input levels of phosphorus and nitrogen have been at the lowest since 1977, but for phosphorus the decline is leveling off. In the Southern Wadden Sea (from The Netherlands to Lower Saxony) nutrients loads from the

Rhine and Maas, due to the Northeastern circulation along the Wadden sea, and organic matter produced in the North Sea has caused eutrophication and high chlorophyll levels (van Beusekom et al. 2019). Algal blooms had been increasing since the 1970s and peaked in the 1990s. The Northern Wadden Sea shows a clear decline since then, but the Southern Wadden Sea is still susceptive to big algal blooms due to the higher eutrophication. Consequently, seagrass numbers in the Southern Wadden Sea are still low, but nutrient load reduction could help them recover (van Beusekom et al. 2019). The Dutch government has implemented recovery-measurements for *Z. marina* in the Dutch Wadden Sea (van Duren & van Katwijk 2015). The habitat seemed suited for the recolonization of *Z. marina* with seeds from the German Wadden Sea and seagrass was growing. However, coverage of seagrass remained low and many seeds were not sprouting, probably due to an until then unknown disease, *Phytophothora gemini* (Man in 't Veld et al. 2011) (different from the wasting disease, mentioned in the next section). The habitat is suitable for seagrass though, suggesting that a full and sustainable coverage can happen with another seeding project and a reduced nutrient load (van Duren & van Katwijk 2015, van Beusekom et al. 2019).

Unlike the seagrass meadows in the Southern Wadden Sea, meadows in the waters of North Frisia (Germany) seem to be recovering from the dip in the 1990s. A decrease in the nutrient loads by rivers and the number of storms, causing increased turbidity, in the area seem to be the explanation for this increase (Reise & Kohlus 2008). Dolch et al. (2013) later concluded that intertidal seagrass beds had been persisting in the area ever since the 1930s and confirmed that the declines in this time period happened due to sediment dynamics and eutrophication phases. Eutrophication is not the biggest threat of these meadows anymore, although it should not be forgotten, but an increase in storms and rising sea level could reverse the progress made in the near future (Dolch et al. 2013).

Eutrophication in Danish coastal waters started to rise in the 1950s and reached a peak in the 1980s due to excessive nutrient input by rivers (Conley 2000). Measures were taken in the 1990s to reduce the nutrient input (mainly nitrogen and phosphorus) into the coastal ecosystems. These measures included: improved sewage treatment and rules on the storage of manure and its usage. These measures resulted in increasing water clarity, after the decrease in phytoplankton biomass (Riemann et al. 2016). *Z. marina* fields have expanded their range to deeper waters in recent years (Riemann et al. 2016), until 2007/2008 the meadows were shrinking towards shallower waters, but since then they have been expanding towards deeper waters with the water clarity increasing comparatively (Riemann et al. 2016). The slow response of seagrass meadows to the measures can be attributed to the positive feedback loop seagrass has with the sediment it grows on; the seagrass meadows first stabilize the sediment and this facilitates the expansion of the meadow (Riemann et al. 2016). Because of disappearance of seagrass due to eutrophication new meadows had a hard time to form and succeed, with the surviving well established meadows also being the first to reach deeper again.

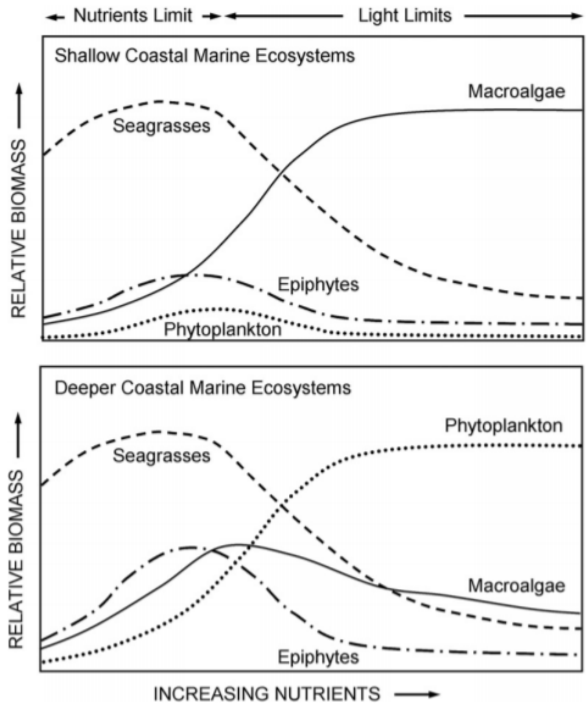

Figure 3. General effect of eutrophication on both shallow and deeper coastal marine ecosystems*. Seagrass (and epiphyte) biomass increases shortly and then declines with increasing nutrients in both ecosystems. Consequently, macroalgae biomass increases in shallow systems and phytoplankton biomass in deeper systems. With increased nutrient load both ecosystems shift from a seagrass dominant system to a macroalgae dominant (shallow) and phytoplankton dominant (deeper) system respectively (Burkholder et al. 2007).*

Rask et al. (1999) researched the Danish Action Plan for Aquatic Environment (APAE) in the waters surrounding Funen (Eastern Danish coast). This plan included measures to reduce nitrogen run-off by 50% and phosphorus run-off by 80%. The objectives set by the Danish action plan were achieved on Funen, mainly because of meteorological reasons; there had almost been no precipitation on the island, resulting in a sufficient decrease in nutrient run-off into the surrounding waters. Lower eutrophication resulted in a lower phytoplankton biomass, and thus a decrease of anoxia in the waters near the sea bottom. *Z. marina* had mainly disappeared because of this anoxia resulting from algal blooms, and sulfide release following this anoxia. Water clarity improved because of the measures, allowing *Z. marina* meadows to expand to deeper waters all around Denmark (Rask et al. 1999).

Along the Skagerrak coast of Sweden *Z. marina* meadows were depleted by 58% between the 1980s and 2000, mainly in the shallower parts of the meadows (Baden et al. 2003). The highest loss of seagrass happened in the area with the highest nutrient load in the study area. The high nutrients load caused algal blooms, which might have reduced light penetration and caused anoxia. Algae like *Enteromorpha radiate* have been known to suffocate *Z. marina* (and *Z. noltei*) meadows in other areas, such as Hampshire (United Kingdom) and Funen (Den Hartog 1994, Rask et al. 1999). There were apparent differences between locations around the coast, but these differences could be attributed to water degradation causes other than eutrophication. Oil leakage from boats might be a stressor explaining local *Z. marina* disappearance, for example (Baden et al. 2003). Although recolonization of seagrass can happen through the transplantation of seagrass from existing meadows, Baden et al. stresses that prevention is better than cure and water quality should be improved, just like around Funen (Rask et al. 1999).

Eutrophication affects the Baltic Sea as well (Jansson & Dahlberg 1999) and it should not be neglected as a cause of seagrass meadow degradation (Böstrom et al. 2003). However, seagrass meadows here seem less affected by eutrophication than the Skagerrak meadows (Baden et al. 2010). The biological interactions might help against the negative effects of eutrophication, as the abundant algal mesograzers encounter a relatively low number of predators, allowing them to prevent the algal growths (Boström et al.

2003). The abundance of mesograzers in the Baltic sea may therefore prevent this area from being affected by eutrophication like many other Northern European areas were. Overfishing (of the top predatory fish) might be a reason for the excess of intermediate predators in the Skagerrak area and thereby the lack of mesograzers (Baden et al. 2010). Preventing overfishing could therefore ultimately restore the food chain and make seagrass meadows much less vulnerable to eutrophication (Baden et al. 2010).

In the Mediterranean, eutrophication is only being listed as a cause for decline in Italy and not in Spain and France (Airoldi & Beck 2007). *C. nodosa* could survive in the polluted Bay of Thessaloniki (Greece) (Lazaridou et al. 1997). Seagrass meadows in the Mediterranean are historically under-researched and this makes it difficult to gage accurate declines and previous causes for those (Green & Short 2003). In the Northern Adriatic Sea along the coast of Italy eutrophication started in the 1930s, similarly to the Northern European countries. Eutrophication reached stressing conditions in the 1960s, while peaking in 1978 based on dinocyst (dormant life-stage of dinoflagellates forming microfossils) abundance (Sangiorgi & Donders 2004). There is not a lot known about the impact of eutrophication on meadows in the Adriatic Sea (and the rest of the Mediterranean) but epiphytes of *P. oceanica* were found to be vulnerable to increasing nutrient concentrations (Balata et al. 2008). With these epiphytes being an integral component of seagrass meadows, the impact of eutrophication on Italian and Mediterranean seagrass meadows should not excluded and underestimated (Balata et al. 2008).

3.2 Wasting disease and invasive organisms

Seagrass meadows are also affected by disease, such as fungal molds, and invasive organisms. The most significant case of disease caused over 90% of the North Atlantic *Z. marina* population to disappear (Muehlstein 1989). Invasive marine flora, such as algae and seaweed, can also outcompete and affect seagrass, causing declines.

In the 1930's *Z. marina* fields in Europe (and North America) were infested by an until then unknown disease, later identified as *Labyrinthula zosterae*, a slime mold. Some of these seagrass beds survived in high salinity areas, due to a higher salinity tolerance of *Z. marina* than *L. zosterae* (Durako et al. 2003). Slime molds exist naturally in seagrasses as a decomposer. Other factors resulting from human influence, such as pollution, were attributed to have facilitated this disease by changing environmental conditions and weakening seagrass, to the point where it could waste seagrass meadows (Milne & Milne 1951). In the Dutch Wadden Sea, for example, the building of the Afsluitdijk (see next section) has likely helped the slime mold infest seagrass, causing it to disappear from this part of the Wadden Sea (Den Hartog 1987).

Between 1994 and 2011 *C. nodosa* meadows declined around the island of Gran Canaria in the Atlantic Ocean. It was concluded that *Caulerpa prolifera*, a green algae, had a significant negative effect on *C. nodosa* (see figure 4), in the plots of *C. nodosa* where the algae were removed the seagrass developed more shoots and had a higher biomass (Tuya et al. 2013). Both species are native to the area and have coexisted, but a large disturbance, a storm for example, has probably tipped the competition in favor of *C. prolifera* (Tuya et al. 2013). However, a different paper by Tuya et al. (2013) states that an increase in the number of storms is not the cause for the decline of *C. nodosa* around Gran Canaria. Human-related activities on the local scale, such as outfalls and fish farms, are said to be the leading cause here, but their exact effects need to be researched (Tuya et al. 2013).

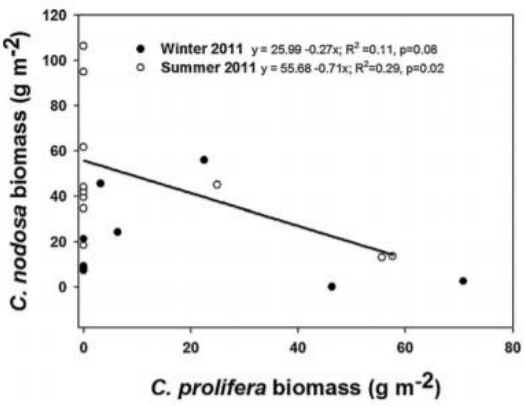

***Figure 4. Relation between C. nodosa and C. prolifera biomass** on the island of Gran Canaria in 2011 (Tuya et al. 2013).*

3.3 Coastal degradation

The modification of the European coast is affecting seagrass meadows by changing the structure of the coast, increasing turbidity and covering or removing the plants (Short & Wyllie-Echeverria 1996).

Kaster & Michaelis (1999) observed a decline of 77% area coverage in both Zostera species in the Wadden Sea of Lower Saxony since the 1970s. The cause of the loss was unknown at that moment, but environmental damage due to anthropological activities was pointed out as the main reason. In the Dutch Wadden Sea *Z. marina* might be absent because of the construction of the Afsluitdijk (together with the wasting disease mentioned in the previous section). Before the completion of the Afsluitdijk the seagrass meadows were already dealing with more turbidity for years because of sediment displacement. When it was closed off in 1932 the tides rose higher than before in the following years, changing the structure of the mudflats and weakening the seagrass. These changes in their habitat would have made the seagrass susceptible to the wasting disease of the 1930s (Den Hartog 1987). The decline of German seagrass meadows near Sylt could be explained by a similar cause, the building and completion of the Von Hindenburgdam. As both the Dutch and German meadows disappeared and did not recover, coastal modification is an important factor in the decline here and together with the wasting disease responsible for the disappearance of *Z. marina* (Den Hartog 1987, Kaster & Michaelis 1999).

3.4 Mechanical damage

Several studies show mechanical damage as an important cause for seagrass decline, for *P. oceanica* in particular (Francour et al. 1999, Abadie et al. 2005, Montefalcone et al. 2008, La Manna et al. 2014). Anchoring and mooring are the two main direct damage-causing activities. Anchoring and boat moorings leave scars in seagrass meadows, affecting the structure of the meadow (Montefalcone et al. 2008). The structure of the meadow was affected in deeper waters and parts with a low seagrass cover, both areas that are less capable to restore the damaged areas. In another experiment Francour et al. (1999) concluded that four out of five parameters for *P. oceanica* cover were positively correlated with moderate to high anchoring pressure: meadow cover, shoot density, proportion of plagiotrophic (horizontally growing) rhizomes and the degree of meadow fragmentation.

In the Urbina lagoon on Corsica *C. nodosa* meadows were estimated to have declined by almost 50% between 1973 and 1994, but greatly recovered in the following years until 2011 (Garrido et al. 2013). The most important factor influencing these fluctuations in *C. nodosa*-numbers was increased turbidity, caused by several factors such as rainfall and dredging. Dredging caused decline of all four seagrass species around Europe, mostly due this increased turbidity. Luckily dredging is easily regulated and has been less of a cause to the decline of seagrass in recent years (Erftemeijer & Lewis 2006).

Mechanical damage caused by anchoring and dredging also impacts the meadows indirectly. Anchoring can affect the chemistry of the substrate where *P. oceanica* is, increasing the concentration of hydrogen sulfide in the soil (Abadie et al. 2016). This increase in hydrogen sulfide in the patches negatively affects the ability of the seagrass to re-colonize this patch, which often causes the gap without seagrass to expand and ultimately changes the seascape (Abadie et al. 2016). Mechanical damage also promoted the spread of an invasive seaweed (*Caulerpa racemosa*) into *P. oceanica* meadows (Ceccherelli et al. 2014). *C. racemosa* colonized the edges of meadows more after the disturbances. The center of the meadows was free of seaweed because the canopy of the seagrass might – by reducing light reaching the seafloor and physically blocking the seeds - block the seaweed from colonizing the center (Ceccherelli et al. 2014). Although the exact effect of invasion by this invasive seaweed of seagrass meadows is still unknown, invasive algae have negatively affected seagrass meadows elsewhere and should not be facilitated if possible (Tuya et al. 2013).

Francour et al. (1999) concluded that recovery of *P. oceanica* is possible, but takes years and the cease of disturbances. Affected meadows need at least five years to reduce the degree of fragmentation and recover, while more heavily damaged meadows might take longer than that to recover (Francour et al. 1999). Elimination of the cause of the mechanical damage is necessary and even then damaged meadows continue to grow slower than unaffected meadows, which may lead to the time for total recuperation of the meadow to be up to 100 years (González-Correa et al. 2005). Because of the direct and indirect damages previously mentioned and this slow recovery time, almost all researchers advised to take management measures to conserve seagrass meadows (Francour et al. 1999, Montefalcone et al. 2008, Collins et al. 2010, La Manna et al. 2015). Some of these management strategies were; restricting anchoring as much as possible, creating a moratorium on anchoring (Francour et al. 1999) and creating a seagrass friendly technology for mooring (Montefalcone et al. 2008), like the permanent ecological moorings along the French coast (Francour et al, 2006). Anchoring and mooring restriction were implemented around the Mediterranean, but did not always prove useful (La Manna et al. 2015). *P. oceanica* meadows continued to be damaged by anchoring and thereby failed to recover. La Manna et al. (2015) advised to create free zones for anchoring where there is no seagrass, to implement local surveillance -because of the incapability to follow restrictions- and to properly educate the public on the ecological importance of seagrass meadows. On the Southern English coast anchoring and mooring also affect *Z. marina*. Unaffected meadows were more cohesive and contained more organic material than those affected by mechanical damage (Collins et al. 2010). Again, recovery takes years and if inadequate measures are taken the meadows might decline (Collins et al. 2010).

Clam harvesting is another kind of mechanical damage highly affecting *Z. noltei* (Cabaço et al. 2005). Although the clam harvesting definitely has a direct effect of the meadows by negatively affecting both shoot density and overall seagrass biomass, *Z. noltei* recovered quickly from disturbances. The rapid growth and production rates acted as a buffer to mechanical damage, taking only a month to recover. Another research in the same area in Southern Portugal also concluded that *Z. noltei* meadows disturbed by clam harvesting, although they were fragmented and lower in shoot density, extended their reproduction period and fertile period to survive the disturbances (Alexandre et al. 2005). Although this is only one area and disturbance might be relatively low, these adaptations to disturbances could be a reason *Z. noltei* is surviving them in Europe.

Causes	Water quality degredation	Wasting disease	Coastal degredation	Mechanical damage
Affected species	*P. oceanica & Z. noltei*	*Z. marina*	*C. nodosa*	Mainly *P. oceanica* and *Z. noltei*, but all species affected
Management measures	Reduction and better treatment of industrial sewage, rules on storage and usage of manure	- (Natural colonization)	-	Anchoring restrictions, seagrass friendly mooring & education
Measure response	Reduced nutrient concentration in the water, but no full recovery of meadow	Recolonization of lost area if possible	Permanent changes in the location of meadows affected hereby	When followed effective to help meadows

Table 2. The effects of the threats and measures on European seagrasses. *In this table the four major causes for decline of seagrass in Europe are listed and the seagrass species most affected by each is/are mentioned. Measures against the threats are mentioned and how the response of seagrass was to these measures*

4. Discussion and conclusion

The four causes previously explained have each had a significant impact on the decline of seagrass meadows in Europe. Wasting disease, which decimated seagrass stocks 90 years ago, and coastal degradation, which helped in the decline of the Wadden Sea meadows, look to be scarce disturbances (Santos et al. 2019). Even though these two causes have not caused recent declines (Santos et al. 2019), they might cause them again and can still affect weakened meadows (Erftemeijer & Lewis 2006, Sullivan et al. 2013). Eutrophication and mechanical damage have been the more recent big threats to seagrass meadows. Even though measures to reduce both have been taken, combating these threats might not be as straightforward as reducing nutrient loads for eutrophication (Baden et al. 2003) and having anchoring restrictions against mechanical damage (La Manna et al. 2015), and other measures are needed. A decline in overfishing could, for example lead to a decline in eutrophication (Baden et al. 2010), which together with the

reducing of nutrient loads from the land might take away this threat.
Water quality degradation has been the leading cause for the decline of seagrasses in Europe in the second half of the 20th century, hence why most management measures have been focused on reducing nutrient loading into coastal waters. This reduction in eutrophication leads to a reduction in nutrient concentration, the first sign of recovery of coastal ecosystems from eutrophication, and also helping seagrass meadows (Riemann et al. 2016). Similar reductions of nutrient concentrations in seagrass ecosystems have been found along the Portuguese (Cardoso et al. 2010) and Catalonian coast (Roca et al. 2015) after regulations for nutrient runoff from the land were put in place, indicating that these do actually help prevent eutrophication and lower nutrients concentrations. Although this might sound promising for the recovery of seagrass in these and other areas affected by eutrophication, in all of these cases seagrass meadows have not fully recovered. Seagrass meadows might not be resilient and full recovery is difficult (Elliott et al. 2007) and it is important to monitor these areas in the future to see if this full recovery, a return to the size the meadows used to be before disturbance, is achieved. Preventing eutrophication seems to be helping the ecosystem and it remains to be seen if seagrass meadows can keep increasing.

Mechanical damage affects seagrass meadows locally, altering their structure and leaving permanent scars in the meadow. It impacts the meadows both in a direct way, by anchoring and mooring, and indirect way, by chemically altering the substrate and promoting invasive seaweed spread. It may take years for the meadow to recover, even when left undisturbed (Francour et al. 1999). The slow-growing *P. oceanica* in particular recovers slowly from anchoring and other disturbances. Regulations to prevent mechanical damage are straightforward, but have to be asserted to be effective. Mechanical damage could be the easiest cause to combat by restrictions, as all disturbances are caused either directly or indirectly by human activity in the area.

In the first half of the 20th century wasting disease was the big cause for the decline of *Z. marina*. There has not been another big wave of wasting disease since, but as Den Hartog (1987) pointed out the disease was probably facilitated by other threats and such a thing could happen again. Other *Labyrinthula* species could also be or become virulent and significantly affect seagrass meadows (Sullivan et al. 2013). The best way to prevent another wasting disease from decimating seagrass is probably to take measures against the other causes. Major coastal builds, like the completion of the Afsluitdijk, and dredging helped in the decline of seagrass. However, measures (such as strict regulations, enforcement, monitoring and environmental friendly dredging techniques) have been taken to prevent coastal degradation from affecting seagrass meadows and these have proven useful (Erftemeijer & Lewis 2006).

Santos et al. (2019) fail to mention any increases due to measures taken against the last three causes, only mentioning the effects of a better water quality. Even though habitat protection is mentioned and should be an important part in protecting seagrasses, no specific solutions for these threats are named. The positive view in this paper is mostly based on fast recovering species and although these do seem to be recovering in contrast to the overall trend of decline in the 20th century, their increase was more imminent than the increase of slow recovering species. Duarte (2002) was correct in predicting that developed countries (like in Europe) would be able to slow down seagrass decline.

In conclusion, I think the future is looking good for seagrasses in Europe, with consistency in research and measures to protect them being key to make a permanent trend reversal.

4.1 Recommendations

Moderate positivity about the current situation of seagrass in Europe is justified, but there is still a lot that can be recommended to improve. Education on seagrass and the importance of seagrass meadows to the coastal ecosystem as a whole should be a number one priority in the conservation of these systems. It is important for the general public to understand the importance of these coastal ecosystems, to both nature and humans. Educating the public could eventually help the current growth of seagrass meadows to increase and become more resilient, able to overcome threats that will undoubtedly continue, like industrial development and subsequent runoff (Grech et al. 2012). Monitoring and updating the management strategies implemented on the meadows might protect them from mechanical damage and water quality degradation.

In these special times during the Covid-19 pandemic it would be interesting to see how the seagrass meadows are doing now, in a time of relative tranquility in their habitats. There is a possibility that they are thriving right now and it would be a perfect moment to implement measures to keep it that way when Covid-19 is behind us. Overfishing is a major indirect threat to seagrass meadows and by reducing the quantity of fish we take from the ocean now we could help the positive trend of seagrass ecosystems.

References

Abadie, A., Lejeune, P., Pergent, G. et al. 2005. From mechanical to chemical impact of anchoring in seagrasses: The premises of anthropogenic patch generation in *Posidonia oceanica* meadows. *Marine pollution bulletin* 109, 61-71.

Airoldi, L. & Beck, M.W. 2007. Loss, status and trends for coastal marine habitats of Europe. *Oceanography and marine biology: an annual review* 45, 345-405.

Alexandre, A., Santos, R. & Serrão, E. 2005. Effects of clam harvesting on sexual reproduction of the seagrass *Zostera noltei*. *Marine ecology progress series* 298, 115-122.

Baden, S., Gullström, M., Lundén, B. et al. 2003. Vanishing Seagrass (*Zostera marina*, L.) in Swedish coastal waters. *Ambio* 32(5), 374-377.

Baden, S., Boström, C., Tobiasson, S. et al. 2010. Relative importance of trophic interactions and nutrient enrichment in seagrass ecosystems: A broad-scale field experiment in the Baltic–Skagerrak area. *Limnology oceanography* 55(3), 1435-1448.

Balata, D., Bertocci, I., Piazzi, L. et al. 2008. Comparison between epiphyte assemblages of leaves and rhizomes of the seagrass *Posidonia oceanica* subjected to different levels of anthropogenic eutrophication. *Estuarine, coastal and shelf science* 79, 533-540.

Biebl, R. & McRoy, C.P. 1971. Plasmatic resistance and rate of respiration and photosynthesis of *Zostera marina* at different salinities and temperatures. *Marine Biology* 8, 48–56.

Borum, J., Duarte, C.M., Krause-Jensen, D. et al. 2004. European seagrasses: an Introduction to monitoring and management. *EU project Monitoring and Managing of European Seagrasses*.

Boström, C., Baden, S.P., Krause-Jensen, D. 2003. The seagrasses of Scandinavia and the Baltic Sea. In Green, E.P. & Short, F.T. *World atlas of seagrasses.* Univeristy of California press.

Cabaço, S., Alexandre, A., Santos, R. 2005. Population-level effects of clam harvesting on the seagrass *Zostera noltei*. *Marine ecology progress series* 298, 123-129.

Cardoso, P.G., Leston, S., Grilo, T.F. et al. 2010. Implications of nutrient decline in the seagrass ecosystem success. *Marine pollution bulletin* 60, 601-608

Ceccherelli, G., Pinna, S., Cusseddu, V. et al. 2014. The role of disturbance in promoting the spread of the invasive seaweed *Caulerpa racemosa* in seagrass meadows. *Biological invasions* 16, 2737-2745.

Collins, K.J., Suonpää, A.M., Mallinson, J.J. 2010. The impacts of anchoring and mooring in seagrass, Studland Bay, Dorset, UK. *Underwater technology* 29:3, 117-123.

Conley, D.J. 2000. Biochemical nutrient cycles and nutrient management strategies. *Hydrobiologia* 410, 87-96.

Conolly, R.M. 1997. Differences in composition of small, motile invertebrate assemblages form seagrass and unvegetated habitats in a southern Australian estuary. *Hydrobiologia* 346, 137-148.

De los Santos, C.B., Krause-Jensen, D., Alcoverro, T. et al. 2019. Recent trend reveral for declining European seagrass meadows. *Nature communications* 10, 1-8.

Den Hartog, C. 1987. "Wasting disease" and other dynamic phenomena in *Zostera* beds. *Aquatic botany* 27, 3-14.

Den Hartog, C. 1994. Suffocation of a littoral *Zostera* bed by *Enteromorpha radiata*. *Aquatic botany* 47, 21-28.

Dolch, T., Buschbaum, C. & Reise, K. 2013. Persisting intertidal seagrass beds in the northern Wadden Sea since the 1930s. *Journal of Sea Research* 82, 134-141.

Duarte, C.M. 2001. Seagrass Ecosystems, in S. L. Levin, *encyclopedia of biodiversity*, vol. 5. Academic press, 255-268.

Duarte, C.M. 2002. The future of seagrass meadows. *Environmental Conservation* 29, 192-206.

Durako, M., Zieman, J., & Robblee, M. 2003. Seagrass ecology. In W, Nuttle, J. Hunt & M. Robblee (eds), *A systhesis of research on Florida Bay*, Florida Bay science programma/US geological survey, pp. 7.1-7.36.

Elliott, M., Burdon, D., Hemingway, K.L. et al. 2007. Estuarine, coastal and marine ecosystem restoration: confusing management and science – a revision of concepts. *Estuarine, coasal and shelf science* 74, 349-366.

Erftemeijer, P.L.A., Lewis III, R.R.R. 2006. Environmental impacts of dredging on seagrasses: a review. *Marine pollution bulletin* 52, 1553-1572.

Francour, P., Ganteaume, A. & Poulain, M. 1999. Effects of boat anchoring in *Posidonia oceanica* seagrass beds in the Port-Cros National Park (north-western Mediterranean Sea). *Aquatic conservation: marine and freshwater ecosystems* 9, 391-400.

Francour, P., Magréau, J. F., Mannoni, P. A. et al. 2006. Management guide for Marine Protected Areas of the Mediterranean Sea, permanent ecological moorings. *Université de Nice-Sophia Antipolis & Parc National de Port-Cros, Nice*, 68-p.

Garrido, M., Lafabrie, C., Torre, F. et al. 2013. Resilience and stability of *Cymodocea nodosa* seagrass meadows over the last four decades in a Mediterranean lagoon. *Estuearine, coastal and shelf science* 130, 89-98.

Gónzalez-Correa, J.M., Bayle, J.T., Sánchez-Lizaso, J.L. et al. 2005. Recovery of deep *Posidonia oceanica* meadows degraded by trawling. *Journal of experimental marine biology and ecology* 320, 65-76.

Grech, A., Chartrand-Miller, K. Erftemeijer, P. et al. 2012. A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. *Environmental research letters* 7, 1-8.

Green, E.P. & Short, F.T. 2003. *World atlas of seagrasses.* Univeristy of California press.

Hemminga, M.A. & Duarte, C.M. 2000. *Seagrass Ecology*. Cambridge University Press.

Jackson, E.L., Rowden, A.A., Attrill, M.J. et al. 2001. The importance of seagrass as a habitat for fishery species. *Oceanography and Marine biology: An annual review 39:* 269-303.

Jansson, B.O., & Dahlberg, K. The environmental status of the Baltic Sea in the 1940s, today, and in the future. *Ambio* 28:4, 312-319.

Kaiser, M.J., Attrill, M.J., Jennings, S. et al. 2011. *Marine ecology: processes, systems and impacts*. Oxford University Press, 290-303.

La Manna, G., Donno, Y., Sarà, G. et al. 2014. The detrimental consequences for seagrass of ineffective marine park management related to boat anchoring. *Marine Pollution bulletin* 90, 160-166.

Lee, S.Y., Fong, C.W. & We, R.S.S. 2001. The effects of seagrass (*Zostera japonica*) canopy structure on associated fauna: a study using artificial seagrass units and sampling of natural beds. *Journa of Experimental Marine Biology and Ecology* 259, 23-50.

Man in ‘t Veld, W.A., Rosendahl, K.C.H.M., Brouwer, H. et al. 2011. *Phytophthora gemini* sp. nov., a new species isolated from the halophilic plant *Zostera marina* in the Netherlands. *Fungal biology* 115, 724-732.

Milne, J.L & Milne, M.J. 1951. The eelgrass catastrophe. *Scientific American* 184:1, 52-55.

Montefalcone, M., Chiantore, M., Lanzone, A. et al. 2008. BACI design reveals the decline of the seagrass *Posidonia oceanica* induced by anchoring. *Marine pollution bulletin* 56, 1637-1645.

Muehlstein, L.K. 1989. Perspectives on the wasting disease of eelgrass *Zostera marina*. *Diseases of aquatic organisms* 7, 211-221.

Ondiviela, B., Losada, I.J., Lara, J.L. et al. 2014. The role of seagrasses in coastal protection in a changing climate. *Coastal engineering* 87, 158-168.

Rask, N., Pedersen, S.E. & Jensen, M.H. 1999. Response to lowered nutrient discharges in the coastal waters around the island of Funen, Denmark. *Hydrobiologia* 393, 68-81.

Reise, K. & Kohlus, J. 2008. Seagrass recovery in the Northern Wadden Sea?. *Helgol Mar Res* 62, 77-84.

Riemann, B., Carstensen, J., Dahl, K. et al. 2016. Recoery of Danish coastal ecosystems after reductions in nutrient loading: a holistic ecosystem approach. *Estuaries and coasts* 39, 82-97.

Roca, G. Alcoverro, T., de Torres, M. et al. 2015. Detecting water quality improvement along the Catalan coast (Spain) using stress-specific biochemical seagrass indicators. *Ecological indicators* 54, 161-170.

Sánchez-Lizaso, J.L., Romero, J., Ruiz, J. et al. 2008. Salinity tolerance of the Mediterranean seagrass *Posidonia oceanica*: recommendations to minimize the impact of brine discharges from desalination plants. *Desalination* 221, 602-607.

Short, F.T. & Wyllie-Echeverria, S. 1996. Natural and human-induced disturbance of seagrasses. *Environmental conservation* 23, 17-27.

Sangiorgi, F. & Donders, T.H. 2004. Reconstructing 150 years of eutrophication in the north-western Adriatic Sea (Italy) using dinoflagellate cysts, pollen and spores. *Estuarine, coastal and shelf science* 60, 69-79.

Sullivan, B.K., Sherman, T.D., Damare, V.S. et al. 2013. Potential roles of *Labyrinthula* spp. in global seagrass population declines. *Fungal ecology* 6:5, 328-338.

Tuya, F., Hernandez-Zerpa, H., Espino, F. et al. 2013. Drastic decadal decline of the seagrass *Cymodocea nodosa* at Gran Canaria (eastern Atlantic): Interactions with the green algae *Caulerpa prolifera*. *Aquatic botany* 105, 1-6.

Tuya, F., Ribeiro-Leite, L., Arto-Cuesto, N. et al. 2013. Decadal changes in the structure of *Cymodocea nodosa* seagrass meadows: Natural *vs.* human influences. *Estuarine, coastal and shelf science* xxx, 1-9.

Unsworth, R.K.F., McKenzie, L.J., Collier, C.J. et al. Global challenges for seagrass conservation. *Ambio* 48, 801–815.

Van Beusekom, J.E.E., Carstensen, J., Dolch, T. et al. 2019. Wadden Sea Eutrophication: long-term trends and regional differences. *Frontiers in marine science* 6:370.

Van Duren, L.A. & Van Katwijk, M.M. 2015. Herstelmaatregel groot zeegras in de Nederlandse Waddenzee. *Deltares.*