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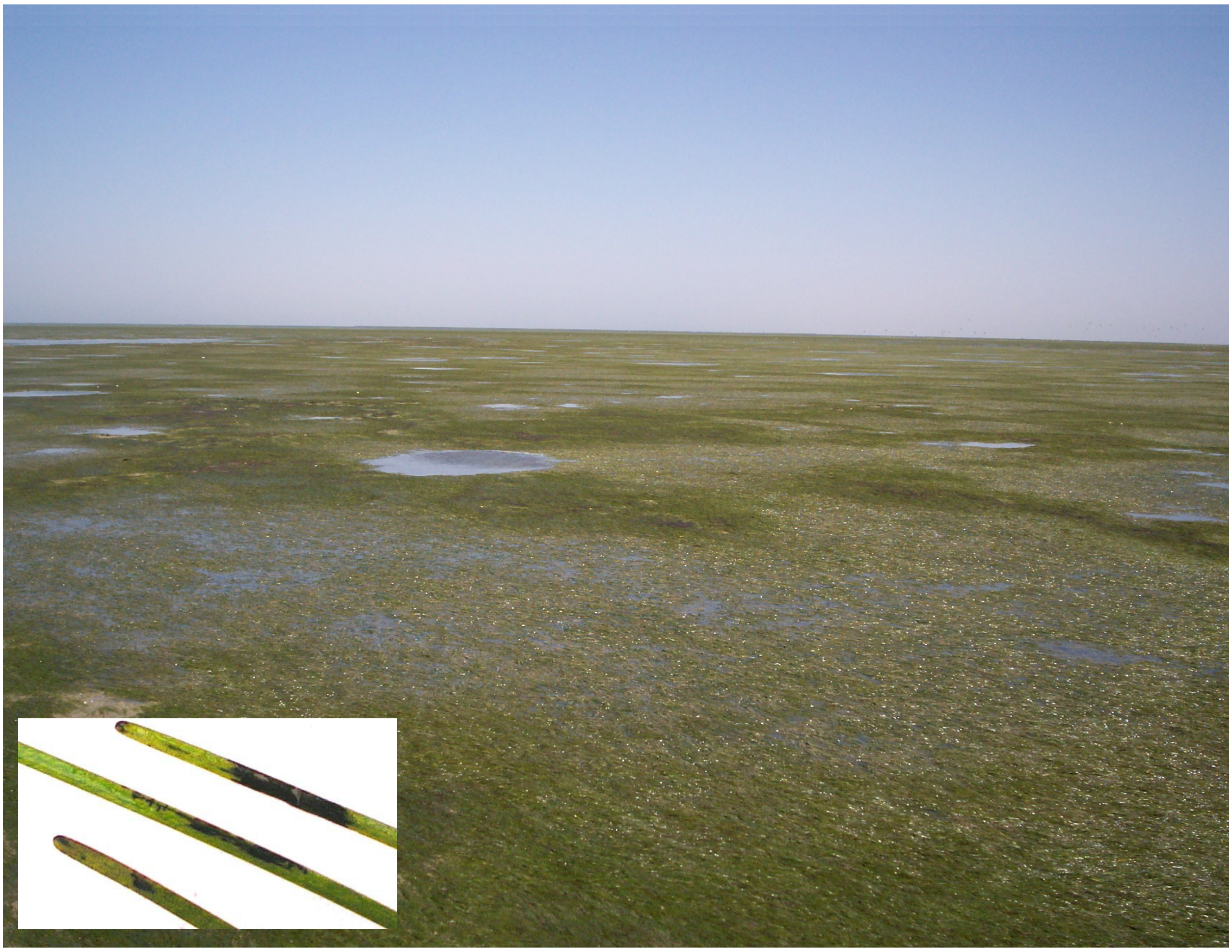

Why the seagrass *Zostera marina* L. disappeared from the Dutch Waddensea

By J. van Eerbeek (S1758675)*

Bachelor Thesis

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Abstract / Samenvatting

From the 1930's onwards the once abundant eelgrass *Zostera marina* decreased to near extinction in the Dutch Waddensea. It was a combination of natural and anthropogenic causes which caused a bare alternative state. Work of three different sets of authors is reviewed. To gain insight in; the situation before the 1930's and the anthropogenic causes which where on the base of the decline in eelgrass, such as the construction of a large dam, the article of de Jonge *et al.* (1996) was selected. Information on the natural treats, such as the wasting disease, is highlighted out Ralph & Short (2002). The present state of the *Z. marina* population was obtained out of the articles of van der Heide (mainly 2007). We wondered what the main culprit in the decline of *Z. marina* was. And what we could do to get it back. An overview of previous restoration schemes is provided and possibilities are given to improve new restoration efforts together with some suitable locations. In the end the author concludes that restoration within the Waddensea must be possible within a certain framework of parameters, such as turbidity and flow velocity.

Sinds de jaren 30 van de vorige eeuw is het eens zo veelvuldig voorkomende groot zeegras *Zostera marina* gedecimeerd tot het niveau dat het bijna uitgestorven is. Het was een combinatie van natuurlijke en antropogene oorzaken die een kale alternatieve staat achter liet. Het werk van drie verschillende auteurs is herbekeken. Om inzicht te verwerven in de situatie voor de jaren '30 en de antropogene oorzaken die aan de grondslag lagen van de achteruitgang van de groot zeegras populaties, zoals de bouw van de afsluitdijk, werd het artikel van de Jonge *et al.* (1996) gebruikt. Informatie over de natuurlijke oorzaken die een bedreiging vormen zoals ziekten werd verkregen uit Ralph & Short (2002). De tegenwoordige staat van de *Z. marina* populatie werd verkregen uit de artikelen van; van der Heide (voornamelijk 2007). We vroegen ons af wat de hoofd veroorzaker was van de achteruitgang van de *Z. marina* stand en wat we zouden kunnen doen om het terug te krijgen. Een opsomming van voorgaande restoratie-programma's is gegeven en de mogelijkheden voor het verbeteren van nieuwe restoratie-programma's zijn beschreven tezamen met enkele mogelijke locaties. Aan het eind wordt de conclusie gegeven dat restoratie van de Waddenzee populatie mogelijk moet zijn binnen een raamwerk van parameters zoals troebelheid en stroomsnelheid.

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Introduction

Seagrasses

Seagrasses are marine angiosperms (family of Potamogetonaceae) and form an ecological group, as they have evolved out of several lines of terrestrial monocots and are not part of a single lineage (Reusch *et al.* 2000). As a polyphyletic group seagrasses are not particularly diverse, being made up of about 50 to 60 species spread over 12 genera (Olsen 2007). Seagrasses are ecologically successful and highly productive (Phillips & McRoy 1980; Gullstrom *et al.* 2002) meadow-forming bioengineers, which serve a keystone function for complete and very diverse ecosystems (Procaccini *et al.* 2007). Seagrasses occur in tropical as well as temperate zone's (van der Heide *et al.* 2009) and serve as a nursing ground for several fish species (van Goor 1919; de la Morinière *et al.* 2002) and molluscs (Polte *et al.* 2005; Orth *et al.* 2006), which in turn provide valuable foraging grounds for millions of migratory birds (Bortolus *et al.* 1998; Jansen 2008). Therefore seagrasses are major contributors to the maintenance of biodiversity (Edgar *et al.* 1994; Boström 2000).

Biobuilders / Bioengineers

Seagrasses are labelled ecosystem engineers because they partly create their own habitat (Bouderesque *et al.* 2009). The root systems of seagrass trap sediment and are a valuable asset to costal barrier defences by reducing the effects of wave-erosion to shores (Hemminga & Duarte 2000; Bruno & Bertness 2001; Williams & Heck 2001). With this sediment trapping function seagrasses improve their own growing conditions (Bos & van Katwijk 2007, van der Heide *et al.* 2007, 2008). Seagrass fields create a deviation of the prevailing currents and reduce flow speeds, in these stills, the sediment settles and gets trapped which increases the water clarity (van der Heide *et al.* 2007). Seagrasses require some of the highest light levels of any plant group (Dennison *et al*. 1993) therefore clear water is most important. One can see that this is a vulnerable dependence that easily is broken by a decrease in water clarity or a decline in seagrass fields.

Seagrass ecosystems also provide various goods and services to humankind including fishing grounds (Burk *et al.* 2001) which makes a profit of $ 3,500 $Ha.y^{-1}$ (Watson *et al.* 1993). The leaves its selves can be harvested and used as an insulation source in walls of houses, as fertiliser in agriculture and as a weaving material to produce baskets, chair seating's and other paraphernalia (van der Vlis 1975; van Katwijk 2003; Wolff 2005). The ocean currently absorbs 25% of global CO_2 emissions and therefore fixes greenhouse gasses and emissions. Seagrasses account for up to15% of the total oceanic CO_2 fixation (Duarte *et al.* 2005).

Zostera marina

This thesis focuses on the eelgrass, *Zostera marina* and its occurrence in the Dutch Waddensea. *Zostera marina* is the most studied and widely distributed seagrass species within the northern hemisphere (Olsen *et al.* 2004; Procaccini *et al.* 2007). It has a growth season from May till September and tolerates wide varieties in salinity (5‰ around Finland till maximal 35‰ in the Atlantic Ocean) although it prefers brackish conditions (Giessen *et al.* 1990b). The Dutch Waddensea has an average of 30‰ and thus falls within the suitable range (van der Heide *et al.* 2006).

Eelgrass is a protogynous hermaphrodite, producing seeds in spates containing differentially maturing male and female flowers producing negatively buoyant seeds (Waycott *et al*. 2006), which can be transported over large distances by the prevailing sea currents. Seagrasses also reproduce asexually through rhizomes and shoots (Hemminga & Duarte 2000). These rhizomes and shoots also provide the seagrass with a horizontal dispersal mechanism (Hemminga & Duarte 2000). A single genet may consist of several genetically identical shoots or ramets; the expanded collection of ramets forms the clone. Genets and ramets form large dense meadows in the field and identification of relatedness is only possible through genetic genotyping (Coyer *et al.* 2008). When a section of seagrass is dislodged it can settle in new suitable locations. Because seagrasses form large clones they are likely to be more subdued to inbreeding depression (Williams 2001).

Halfway the 20th century *Z. marina* was a very common occurring plant within the Dutch Waddensea (van Goor 1919) (Fig. 1). At the beginning of the 20th century eelgrass meadows in the Waddensea and Zuiderzee covered an area of more than 150 km^2 (van Goor 1919). Seagrass was so abundant that it was widely used by the Dutch population as insulation material and fertilizer (van der Vlis 1975; van Katwijk 2003; Wolff 2005). The former island Wieringen actually thanks its name to the seagrass (wier means water plant in Dutch). In the 1930's a large dam was constructed (Afsluitdijk) and the distribution of eelgrass significantly declined (den Hartog & Polderman 1975; van den Hoek *et al.* 1979), and reached its lowest point in the 1990's (de Jonge *et al.* 1996)

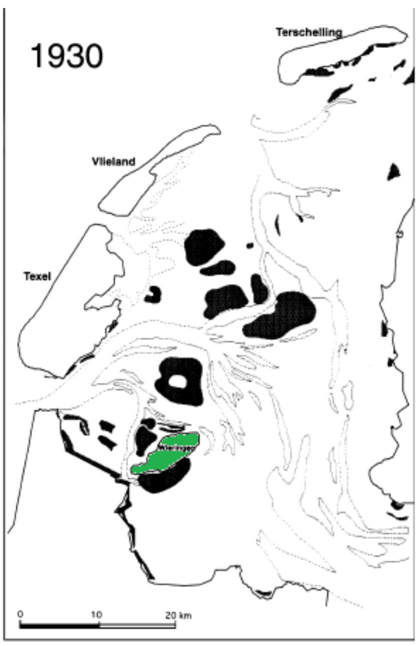

Figure 1. Seagrass distribution (black areas) within the western Waddensea in the 1930's, The former island of Wieringen is highlighted in green (Reigersman, 1939 in de Jonge *et al.* 1996).

Nowadays *Zostera marina* is rare and endangered, and the only spots where it is found within the Dutch Waddensea are two very small but quite stable locations (mudflats “de Paap” and “Voolhoek” near Eemshaven) in the mouth of the river Ems (de Jong, personal communications, in van Eerbeek 2009) (Fig.2) .

Figure 2. Present distribution of *Zostera marina.* Green square shows two stable locations in the Ems estuary (de Paap en Voolhoek). The green circle illustrates some tufts of *Z. marina*. Within the yellow square *Z. marina* is occasionally found. The orange square gives the location of a reintroduction site. All orange blocks and circles are Rijkswaterstaat seagrass monitoring points. The Afsluitdijk (dam), between Noord-Holland and Friesland, is clearly visible. Showing the IJsselmeer (former Zuiderzee) in clear blue.

Natural threats

During the Last Glacial Maximum (LGM 18,000–10,000 years BP) ice covered most of the North Atlantic including the Dutch coast (Clark & Mix 2002), forcing most northern species to southern refugia, from which the populations expanded as the ice receded (Olsen *et al.* 2004).

More recently, another ecological and genetic bottleneck occurred in the form of the 'wasting disease' (Short *et al.* 1987; Muehlstein *et al.* 1991). In the 1930's, the protist *Labyrinthula zosterae* (phylum Labyrinthulomycota, Muehlstein *et al.* 1991), caused photo-inhibition and necrosis to seagrass-leaves (Ralph & Short 2002). The wasting disease struck within the whole Atlantic basin, infected the eelgrass with black spots, and eliminated 90% of the *Z. marina* populations along the American and European coasts (Muehlstein 1989). Most of the American and Canadian populations recovered quite fast from the wasting disease, partly due to restoration efforts. Recovery along northern European coastlines took much longer (Short *et al*. 1986, 1988, 1993). Populations in France and the Baltic took years to recover; the Dutch Waddensea population never recovered and vanished (Giessen *et al.* 1990a, b) up to a few small relict populations (Fig. 2).

Anthropogenic threats

In the past decade, natural and anthropogenic factors, such as dredge fishing, the increase of nutrient loads, and the decline in water clarity, caused a ~15% worldwide decline seagrass areal (Short & Wyllie-Echeverria 1996; Green & Short 2003).

Clearly, the LGM, wasting disease and mass mortality due to anthropogenic causes represent major bottlenecks in the population genetics of *Z. marina* and lead to questions about the genetic viability, recovery capacity and long-term consequences of genetic erosion (Williams 2001). Therefore we can ask ourselves:

"What made the Dutch seagrass fields so susceptive to the wasting disease?"
What was the main cause of its disappearance?
And what can we do to restore it?

Methods

In this thesis I will give an overview of the past, present en and possible future scenarios for the reintroduction of *Zostera marina* meadows, based on the current literature.

Results

Anthropogenic causes

In their **review article de Jonge *et al.* (1996)** highlighted the decline of *Zostera marina* in the Waddensea due to **anthropogenic causes**. In the 1930's the water in the Waddensea experienced a major decline in water clarity due to the construction of the Afsluitdijk. This dam was constructed from North-Holland to Friesland and separated the former Zuiderzee (nowadays a freshwater basin and called the IJsselmeer) from the Waddensea (van Katwijk 2003). This was done to increase the safety of the Dutch low-lying coasts and large sections of land where reclaimed of the IJsselmeer in order to create fields for agriculture. At the finishing of the Afsluitdijk project the water currents, flow speeds, tidal amplitudes and the salinity in the "new Waddensea" where altered in a negative way for eelgrass meaning that they all increased dramatically (van den Hoek *et al.* 1979; Reigersman 1939 in Giessen *et al.* 1990b). The original tidal amplitude of about 1.2 m^{-1} suddenly increased by 15-25 cm in the tidal inlets and 30-50 cm at the upper ends of the Marsdiep (the entrance of the Waddensea near the island of Texel) (de Jonge & de Jong 1992). The clarity of the water also declined due to the erosion of sediment and it became murky (Giessen *et al.* 1990a). Fishing for cockles (*Cerastoderma edule*) by suction dredging destroyed seagrass fields in their totality (de Jonge & de Jong 1992) and stirred up massive loads of sediment, under pressure of scientist's NGO's and public, the mechanical cockle fishing was banned from the Dutch Waddensea on 1 January 2005 (Swart & van Andel 2008). De Jong *et al.* (1996) also state that the mowing of eelgrass shoots by mussel seed fisheries can be even more devastating. The cutting of the shoots in May causes a shortening of the growing season which leads to low seed production, this harms recruitment in following years, as was observed in the Ems estuary in the 1980's. As the Dutch population mainly consists of perennials which have low seed production cutting can be most devastating (Keddy 1987). Salinity was changed by the construction of the Afsluitdijk in such a way that the discharge of fresh water from the former Zuiderzee now occurs through two sluices which give immense fluctuations of 23‰ to 2‰ (Vethaak 1992) in salinity when fresh water is discarded. But feedbacks of eelgrass to salinity have never been studied (van der Heide 2006). In their article de Jonge *et al.* (1996) review two field experiment which try to restore eelgrass meadows just south of the island of Terschelling. Both experiments failed to produce any significant growth and the conclusion was drawn that water turbulence was the main stressor responsible for the disappearance of seedlings, complete plants and their rhizomes. They concluded that eelgrass restoration must be possible in sheltered areas "such as the Mok bay" on Texel.

In order to estimate **the differences in water clarity, before and after the 1930's, van der Heide *et al.* (2007)** compared two data sets consisting of *Z. marina* distribution maps from the 30's and a dataset on water quality in the Waddensea spanning the 26 years between 1980 and 2005. They constructed the vertical light attenuation based on the historical eelgrass distribution, because data on turbidity from that era where unavailable. To establish the threshold values for eelgrass to maintain itself they used the 5% percentile of the early 1930's eelgrass distribution measured in meters below Mean Water Level (MWL). Van der Heide *et al.* (2007) used the Lambert-Beer equation, which is a measure for the light absorption based on the properties of the material trough which the light is travelling, to measure attenuation. The historical depth distribution was determined by digitizing maps of eelgrass distribution, tides and depths, available from the 30's. The maps where spatially analyzed by means of a Geographical Information System (GIS) at a 20 x 20 meter resolution. They related the vertical light attenuation to suspended matter to see the influence of suspended sediment and phytoplankton on the water column turbidity. The year averaged values of the 26 year dataset, in which 13 sampling locations where sampled 4 times a year, where used as parameters. Turbidity factors where related to depth to compensate for the wind and wave driven resuspension of sediments in the channels and on the flats.

The results of this study indicate that 90% of the seagrass, in the 1930's, must have been growing in the sub tidal zone between 0.5-2.3 m below MWL. The median range was 1 m below MWL and the vertical light attenuation was 1.2 m^{-1} inside the eelgrass beds. A good fitted correlation was found between vertical light attenuation and suspended matter. Both parameters correlated well with depth. Current mean turbidity was found to be 6.8 m^{-1} indicating a 6 time increase since the 30's. The turbidity of the water entering the Waddensea "only" increased by 2-3 times meaning that things changed within the shallow Waddensea itself. The water entering the Waddensea at present day has the same clarity as the water on the shallows in the 1930's (van der Heide *et al.* 2006) suggesting suitable conditions for restoration and recovery.

To prove the hypothesis that the increase in turbidity was due to an absence in eelgrass meadows, and therefore a decrease in sediment retention capacity, a simple model was created. This model includes the sediment related water clarity and eelgrass shoot density based on logistic growth. The model takes the maximum gross growth rate, carrying capacity and light limitation into account, as well as, constant mortality (due to senescence) and intra specific competition. The default parameter settings of the model were set to mimic average Waddensea conditions. The parameter values where increased in small steps. After each small increase the model was ran till it stabilized at its equilibrium. Equilibrium points where plotted in a graph to visualize a discontinuity. This was also done in a backward manner, decreasing the parameters values. By use of the model two stable equilibria where found. One was a bare state in which eelgrass did not occur. The state in which eelgrass did occur, had a threshold value of 988 shoots.m^{-2}, above this value the population would be most likely to increase up to carrying capacity (3,370 shoots.m^{-2}). Below the threshold the system would collapse to the bare state. Seagrass meadows could hold under the water flow velocities at present day, but the population collapses when the shoot density falls below a certain threshold, past the bifurification point, and the population can not reduce the water velocity enough to keep the water clarity up. When sediment loads are low the water current velocity can be quite high and still maintain occurrence of *Z. marina*. But when sediment loads increase above 108 g.m^{-3} light penetration is to low to sustain eelgrass. The study of van der Heide *et al.*

(2007) also suggest that due to longer emersion periods, due to the increase of tidal amplitude by the closure of the former Zuiderzee, the eelgrass suffered to much from desiccation in the most low-lying locations. They suggest that the poorer light conditions where caused by dredging and sediment extraction activities for the Afsluitdijk project. They conclude that eelgrass recovery, however difficult, must be possible in some optimal sheltered locations where concentrations of suspended solids are low.

Next to the decreased water clarity the increase in influx of land based agricultural nutrients (especially phosphorous) into the marine realm, which increased seven fold between 1948-1975 (Gieskes and Kraay 1977 in Giesen *et al.* 1990b) triggered eutrophication and phytoplankton blooms which together with the ongoing fisheries for molluscs and demersal fish by means of trawling the bottom and is constantly resuspending the sediment further deteriorated the clarity of the water column (Orth *et al.* 2006). The influx of nutrients could cause macro algae to grow on a faster rate, outcompeting the seagrass (Twilley *et al.*1985; Kemp *et al.* 2005). The influence of phytoplankton on water column turbidity seems negligible for the Waddensea, as is the influence of the fluvial input of the river Rhine (van der Heide *et al.* 2007).

Natural causes

Ralph and Short (2002) focussed on the natural stressor *Labyrinthula zosterae*, the caussive agent of the waisting disease. It is suggested by many scientists that the protist *L. zosterae* is always found in seagrass systems but it only emerges when the system is stressed by external factors (e.g. Young 1937, Tutin 1938 and Rasmussen 1977). It is believed that *L. zosterae* functions as a secondary decomposer and emerges in a more mild form when a senescent leaf shoot ages and decays (den Hartog 1987, 1996) forming black slimy spots (see insert on cover). Healthy leaves should not be subdued to the wasting disease because they have the capability and health to fend it off (Vergeer & den Hartog 1994). It has been proved that the salinity in the surrounding water acts as an agent in regulating disease activity (Burdik *et al.* 1993) but the precise mechanism triggering the wasting disease outbreak are yet to be discovered (Ralph and Short 2002). These authors emphasise on the extent in wich *L. zosterae* causes photosynthetic impairment beyond the diseased and blackened leaf tissue. They set up a mesocosm experiment in which they kept eelgrass under natural conditions in a green house. The experiment was started eight months in advance of the measurements. In these eight months *L. zosterae* was granted time to spread to all shoots inside the mesocosms. As a control Ralph and Short (2002) used mesocosms which contained disease free shoots. They used a PAM fluorometer, which is an instrument for studying in situ photosynthesis, to establish a disease profile along an infected leaf blade and to see the photo inhibition above and below the disease bands (the black spots so characteristic for *L. zosterae*). Healthy leaf samples where infected with the protist to monitor the speed of the black spot migration over the length of the leaf. Healthy leafs where used as an agent for the control measurements to show that the response was not due to senescence. Rapid light curves where used to describe the relation between electron transport rate and light irradiance. Electron transport rate (ETR) is dependant on the maximum quantum yield which is an indication of the amount of photo system reaction centres that are capable of converting captured light into energy. It thus gives the rate of electrons which can be transported within leaf tissue by a certain amount of solar irradiance.

As results of their study Ralph and Short (2002) found significant reduced photosynthetic activity in green tissue of up to 4 mm away from a diseased, blackend, region. Showing that effects of the disease extend beond the blackend regions. The maximum quantum yield of a leaf area, acropetal to black patches that extend across the entire with of the leaf, was significantly reduced over the maximum qantum yield of the corresponding basipetal region, thought the acropetal leaftiussue remains green. The speed with wich the disease moved trough the infected leaftissue was at a constant rate of 1 mm.h^{-1} during daylight ours from time 0 (08:00h) till late afternoon (time 10) (Fig. 3). During night the process slowed down and the blackend tissue did not incrase significantly (<0.012 mm.h^{-1}) as the disease frond spread trough the sections of green tissue a decline in effecteive qantum yield was observed.

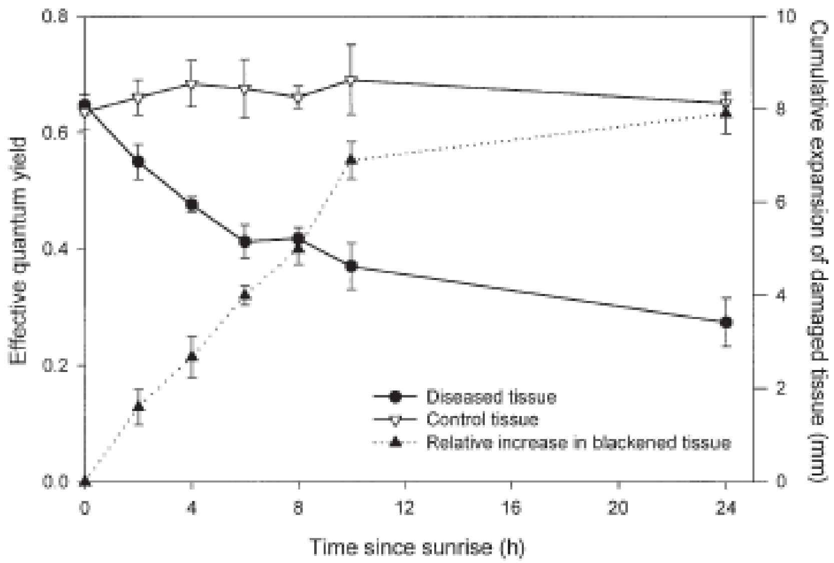

Figure 3. Increase rate in comparison to the effective quantum yield (units are arbitrary). Mean value of the distance of blackened tissue as it expands ± SE (N=6) and effective quantum yield (Ralph and Short 2002).

The blackened tissue was found to show limited photosynthetic activity at low irradiance levels of the rapid light curves. However the curves of healthy tissue showed normal responses to increasing light values with increasing electron transport rate up to 400-800 µmol photon m^{2}.s^{-}1, with down-regulation only occurring at the highest levels of irradiance (1200-1600 µmol photon.m^{2}.s^{-}1) (Fig4.). The tissue at the edge of diseased areas showed increasing ETR at low irradiances (< 200 µmol photon.m^{2}.s^{-}1), at higher irradiances the ETR decreased significantly.

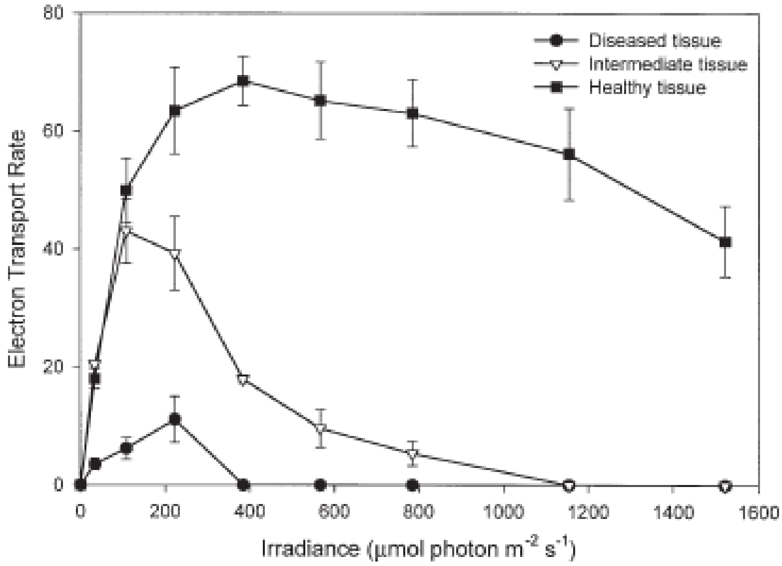

Figure 4. Rapid light curves of diseased, intermediate and healthy tissue samples (SE / N=6). Units of irradiance are µmol photon.m^2.s$^-$1 and of ETR µmol electron.m^2.s$^-$1 (Ralph and Short 2002).

Overnight the photosynthesis did not recover showing that the cause of this response was chronic photo inhibition rather than diurnal down regulation. Healthy tissue samples did not show any signs of down regulation till 1200 µmol photon.m^2.s^{-1}. Some form of transport was impacted by the disease bands because the photosynthetic activity above the diseased band is highly reduced, but weather it was oxygen flow or the flow of photosynthetic products remains unclear. Ralph and Short (2002) conclude with the notion that *L. zosterae* is the primary pathogen of the otherwise healthy green eelgrass tissue.

Protection

Nowadays the Dutch government and nature organizations are far more aware of the anthropogenic and ecological benefits of seagrass than they where in the days of the construction of the Afsluitdijk. Especially Rijkswaterstaat recognizes the value of a thick seagrass barrier protecting the coasts (van der Heide *et al.* 2006, URL 1 and Fig. 2 for monitoring points). The government in general acknowledged the ecosystems functions of seagrass to benefit the deteriorated fisheries. According to the International Union for the Conservation of Nature (IUCN), biodiversity should be maintained and restored at the ecosystems, species and genetics diversity level and all three are crucial to seagrass populations/species (Procaccini *et al.* 2007). As stated above seagrasses provide numerous ecosystem services and are therefore a valuable asset to biodiversity (Procaccini *et al.* 2007). Protection of seagrass meadows may be possible in Marine Protected Area's (MPA's), under proper scientific based management and legislation. The fact that *Z. marina* is a red list species is enough to close area's where it occurs to all anthropogenic activities, on ground of article 20 of the Dutch Nature Protection Act (Natuurbeschermingswet), still entrance of seagrass fields on foot or by boat is unregulated by the Dutch government (van Eerbeek 2009).

Restoration efforts

In the past there have been a series of restoration efforts which failed in restoring seagrass meadows, but gained insight in the cause of failure and underlying mechanisms. With trying, the restoration projects al contributed to science.

In 1987 the Dutch government started with the restoration program of eelgrass in the Waddensea. The government thought this was a necessity because donor populations in the Baltic are situated leeward from the predominantly western winds which reign over the Waddensea. The distribution of seeds by natural dispersal mechanisms seemed impossible (van Katwijk *et al.,* 2010).

In the autumn of 1989 nearly 10.000 eelgrass seeds where planted by hand under the island of Terschelling. The seeds where collected from a population of the German Wadden island of Sylt and where placed 2 cm deep into the sediment in a well defined matrix determined by holes drilled in a PVC plate. The plantation area was protected from winterly gales by a screen of willow shoots. Only 0.5% of the seeds geminated during the following spring and only a single plant developed well during the first growing season (de Jonge *et al.,* 1996).

Between 1992 and 2004 32 transplantations programs have been conducted wit about 32.000 shoots. Only one transplantation program got its plants trough the first growing season. It actually lasted for 8 years and expanded to 5 ha before it got overgrown by macro algae and disturbed by geese (van Katwijk *et al*. 2009).

Discussion & Conclusions

"What made the Dutch seagrass fields so susceptive to the wasting disease?"

It was a combination of anthropogenic causes, the construction of the Afsluitdijk a tremendous increase in fishery practices (cockles and seed mussels) and with that a large shift in abiotic factors, especially the increase in suspended sediment loads, altered flow speeds and most probable fluctuations in salinity that made the stressed eelgrass susceptive to the wasting disease.

"What was the main cause of its disappearance?"

The construction of the Afsluitdijk is seen as the main culprit to the disappearance of the *Z. marina* fields in the Waddensea. The construction of the Afsluitdijk also illustrates why *Zostera marina* made a recovery in the Baltic and recovery was absent from the Waddensea.

"And what can we do to restore it?"

When restoration measures are taken they must at least be in the order of magnitude of several hectares as turbidity in the surrounding bare areas will be high and rhizomatous expansion towards the edges will be slow (van der Heide *et al.* 2007). A temporal clearing of the water column of suspended sediments is found to be the most important measure which must be taken in order to slow down the prevailing currents and make the suspended matter settle on the bottom. This temporal clearing can possible be done by screens of willow shoots, laying mats of artificial biodegradable plastic like seagrass in between the real seagrass is planted. The (temporal) placement of an array of nets provides a possibility as well; it should be further investigated if these nets could be used as a double function with mussel culturing.

An increase in mussels and oyster banks is a possibility as well; Mussels and oysters are filter feeders which increase water clarity, fix sediments and slow down flow velocities.

As possible locations I would like to follow the literature by stating that restoration must be possible in sheltered areas “such as the Mok bay” on Texel (de Jonge *et al.* 1996) and the mudflats under Vlieland and Terschelling in the western Waddensea. Here nutrient regimes, tidal amplitude and salinity are most suitable in these areas (van der Heide *et al.* 2006). The eastern Waddensea is quite suitable if it comes to the parameters tidal amplitude, light availability and salinity but is far more eutrophic than the western part. The fields which are to be established under Terschelling and Vlieland will function as source populations to the eastern Waddensea with the prevailing westerly winds and the Waddensea amphidrome as a dispersal agent.

It is most important that possible protection of eelgrass fields and patches should be arranged under article 20 of the Nature Protection Act, and marine protected area’s (MPA’s) so that further deterioration by boating and mudflat walking are prevented.

When transplanting seagrass, founder effects should be limited as much as possible (Mayr 1942). Scientific based restoration management seeks to know the degree of connectivity and diversity between populations, the locations of source and sink populations and the size of panmictic units to create healthy (meta-)populations (Procaccini *et al.* 2007). For example it would be a waste of time, money and effort if one was to transplant hundreds of eelgrass shoots, from distant locations, if they are all the same genotypicly and/or have low allelic diversity (Williams 2001). Allelic diversity should be as high as possible to fend off future outbreaks of diseases. To preserve *Z. marina* for future generations it is necessary to gain understanding of the phylogeny and genetic buildup of the species within the Waddensea. Modern science is capable of screening individual donor populations for their genetic build up (e.g. Olsen *et al.* 2004).

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