Knowledge for Climate

Potential sensitivity of fen plant species to salinity

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Potential sensitivity of fen plant species to salinity

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Content

1 Summary

Similar to agricultural species, fen plant species can be expected to show different responses to salinity exposure. This report compares available information, including species distribution data, indicator values and experimental studies. A number of fen species (13 – 18 % of occurring species, often more global species) are likely to tolerate brackish conditions and 41 (mostly less global) species are potentially sensitive to chloride concentrations above 100 – 200 mg/L, but uncertainties remain. Distribution data can give limited insight in salinity tolerance ranges of species, although sensitivity may differ from environmental exposure ranges. Also, root zone exposure may differ strongly from surface water salinity. Experimental data could provide more insight, but currently few results from experimental studies on naturally occurring species are available.

2 Samenvatting

Het is te verwachten dat laagveen plantensoorten, net als landbouwgewassen, verschillend kunnen reageren als gevolg van een blootstelling aan zout. In dit rapport worden verschillende typen informatie vergeleken, waaronder verspreidingsdata, indicatiegetallen en experimentele data. Een aantal soorten (13 – 18% van totaal aantal soorten, vooral wijdverspreide soorten) tolereren brakke condities, terwijl 41 andere (minder wijdverspreide) soorten mogelijk gevoelig zijn voor chlorideconcentraties boven 100 à 200 mg/L, maar er blijven onzekerheden. Verspreidingsdata geven een beperkt inzicht in de tolerantiegrenzen, maar gevoeligheid hangt niet altijd samen met verspreiding. Daarnaast kan de blootstelling in de wortelzone verschillen van het zoutgehalte in het oppervlaktewater. Experimentele gegevens zouden meer inzicht kunnen bieden, maar op dit moment is er weinig informatie beschikbaar van experimenteel onderzoek naar wilde plantensoorten.

3 Introduction

In the Dutch polder landscapes, which are mostly used for intensive agriculture, surface water flow and levels are managed thoroughly. Within this landscape some remnants of originally vast fens are currently protected as nature habitats of European importance. However, a modified hydrological system puts constraints on nature management of these areas. In rainy periods water is pumped out of the polders and during droughts water is supplied to the polders from external water systems, in order to maintain constant polder water levels, and in some cases to prevent salinity levels from becoming too high for water use (e.g. by agriculture and nature reserves). This externally supplied water often originates from the River Rhine and contains solutes, such as chlorides and sulphates, and is polluted with nutrients (N, P) as well. For nature management of lowland fens, poor surface water quality is often a point of concern, and various measures are taken to improve it. Additionally, the water salinity has become recently an issue for the water quality in nature areas, especially during periods of sever water shortage. Water managers have a constraint for the maximum allowed salinity level of 200 mg/L chloride for water supplied to polders.

The salinity of water that is supplied to polders, including fen nature areas, has become a subject of debate following recent drought events, such as in the summer of 2003. It was observed that the salinity level of the River Rhine at Lobith is inversely proportionate to its discharge: low water levels correlate with high river salinity levels [Zwolsman & van Bokhoven, 2007]. Closer to the estuary, salinity is additionally determined by sea water intrusion. Sea water level and river discharge strongly influence the intensity and distance of sea water intrusion upriver: low river discharge or high sea water levels correlate with increased salinity levels [Beersma et al., 2005].

Climate change scenarios predict that dry periods in spring and summer may become more frequent and of longer duration, which increases the risk of exceeding the chloride concentration of 200 mg/l [Beersma et al., 2005; Klopstra et al., 2005; Van Beek et al., 2008]. Furthermore, long droughts and higher temperatures imply an increase in water demand by agriculture and natural vegetation, due to high evapotranspiration.

Increased salinity levels may affect nature areas that are located in the Dutch polders. The vegetation of the young terrestrialization stages in the fen landscape (Figure 1) could be potentially sensitive to salinity, because it is affected by surface water, which is influenced by externally supplied water. These fen areas provide a habitat for a high diversity of vascular plant and bryophyte species (up to 30-40 species m^{-2}), as well as characteristic insects, molluscs, fish and mammals, including many threatened fauna and flora species [Schaminée et al., 1995; Verhoeven & Bobbink, 2001].

Figure 1: Landscape of 'fresh water fen banks' [Hennekens et al., 2010]

Figure 2: Landscape of 'brackish water fen banks' (Hennekens et al. 2010)

To understand the potential effects of increased surface water salinity on fen plant species, information is needed regarding the duration and concentration of salt exposure in relation to the response of the plant species. It is currently largely unknown to what degree surface water salinity could increase under the conditions predicted by different climate change scenarios, as this depends on a combination of parameters, including precipitation deficit, river discharge, and water management decisions. One of the worst case scenarios would mean an order of magnitude of 1500 mg/l Cl^- in the supply water during an extreme drought in a W+ climate change scenario [personal communication J. Biesma of Waterschap Rijnland, 2012] .

The actual exposure of the fens depends on many factors, including the amount of supplied water, the structure of the polder water system, and the weather. Evapotranspiration and soil properties control the flow of surface water into the soil. Depending on the zonation of the vegetation, plant species can be exposed to increased salinity levels.

Salinity is one of the determining factors for the direction of fen succession. In brackish environments, the succession of vegetation communities differs from that in fresh water environments (Table 1). These brackish fens are found in coastal marshes that were formerly connected to the sea and in areas that are influenced by saline groundwater. There are differences in species composition between fresh and brackish fens, but there is little known about the response of different functional groups of fen plants or the sensitivity of protected species to elevated salinity levels in surface waters.

Table 1: Succession in fens, depending on abiotic conditions (nutrients and salinity) and management [Verhoeven & Bobbink, 2001]

Sere ***Initial water quality*** **Succession stage**	**Bulrush sere** ***Oligohaline***	**Reed sere** ***Fresh-eutrophic***	**Quagfen sere** ***Fresh-mesotrophic***
Submerged and floating-leaved plants	Najadetum marinae Nitellopsidetum obtusae	Myriophyllo-Nupharetum Utricularietum vulgaris Charetum vulgaris	Potametum lucentis Stratiotetum Myriophyllo verticillati-Hottonietum
Initial floating rafts		Scirpetum lacustris Cicuto-Caricetum pseudocyperi	Cicuto-Calletum
Helophyte dominated fen *Winter mowing*	Scirpetum tabernaemontani	Typho-Phragmitetum Cladietum marisci	Caricetum paniculatae Caricetum elatae
(Floating) brownmoss fen *Summer mowing*			Scorpidio-Caricetum diandrae
Transitional fen, fen heath *Prolonged mowing, atmotrophication*	Pallavicinio-Sphagnetum	Sphagno palustris-Ericetum	
Carr and forest *Absence of mowing*	Salicetum auritae	Carici curtae-Betuletum pubescentis	Thelypterido-Alnetum

Outline of this report

Aim of this report is to compile information that is directly available: scientific literature and databases that can help in understanding the potential responses of fen plant species to increased salinity in the range up to 1500 mg/l Cl^- (brackish). General information regarding salinity tolerance is provided in chapter 4, which will focus on the main ways in which salt can harm plants but will not go into plant physiology. In this report salinity tolerance is approached on the species level, rather than the physiological level. In chapter 5, the use of distribution data and indicator values is discussed and a short list of potentially sensitive species is compiled. Chapter 6 focuses on the information that is available from experiments on non-agricultural plants.

4 Salinity tolerance

Most available knowledge on the effects of salinity on plants comes from crop sciences. Salinity can affect plants in several ways. An overview of the most important effects is shown in Table 2. Salinity sensitivity differs among species, depending on their physiological strategies for dealing with high salt concentrations, but also on other factors, including:

- growth stage (seedlings may be affected when grown plants are not affected);
- salt concentration;
- duration of exposure;
- rate of salinity increase;
- interacting effects (such as water availability and potential evapotranspiration).

Salinity tolerance strategies varies among species. Most fresh water species exclude salt from their roots, in that way preventing toxic amounts of salt from reaching the leaves. Osmotic stress tolerance is found in plants that are adapted to high levels of salinity (e.g. in coastal salt marshes), but also in species that are adapted to drought [Munns & Tester, 2008]. If an increase in salinity affects the hydraulic gradient from soil to root and leaf, a plant can respond by closing stomata, thereby reducing water loss to the atmosphere and an even further decrease of water potential in the soil. Therefore, the observed response of plants to salinity is similar to drought ('physiological drought'). When that happens, plant growth and biomass production are reduced. Salinity tolerant species can respond by increasing the solute concentration in their tissue, which means that cell turgor can be maintained without closing the stomata. In that case, growth continues.

The typical wetland (fen) plants are adapted to grow in permanently wet conditions and can cope with root anoxia. Hypothetically such plants might not be able to adjust to elevated salinity. Although these plants would literally stand in water, elevated salinity could have a similar effect on them as dessication. In low to moderate levels of salinity, and during temporary exposure, the main effect is osmotic, resulting in reduced growth. At higher salinities and longer exposures, accumulating ions in plant tissue will reach a toxicity threshold, resulting in leaf damage . In contrast to most plants, toxicity can occur at low salinity levels (hours to days) for sensitive species that cannot control Na+ transport [Munns & Tester, 2008]. If growth is reduced significantly by salinity stress or if at some point turgor cannot be maintained, a plant may experience competitive disadvantages or may be physiologically damaged. In ecosystems this may lead to a shift in species composition, towards a community of more salt tolerant plants.

Table 2: Main effects of salinity on plants [modified after Munns & Tester 2008]. Some plant species are tolerant to one or more of these effects.

Effects of salinity on plants	Response	Effects	Time until effects occur
Osmotic potential	Reduced water uptake, stomatal closure	Decreased new shoot growth, reduced photosynthesis (per plant, not per leaf area)	Relatively quick: days
Toxicity	Na^+ (and Cl^-) toxicity	'Leaf burning', leaf mortality	Relatively slow: days, weeks
Nutrient interaction	Altered Ca^{2+}, K^+ and NO_3^- uptake	Nutrient deficiency	Depending on growth rate and availability: days, weeks

For agricultural crops, salinity tolerance levels can be identified, as proposed by Maas & Hoffman [1977] by using threshold-response curves, in which yield loss is a function of salinity. These curves show that salinity responses may vary significantly between species. However, very little is known about salinity tolerance of wild plants. For wild plants of fen habitats such curves are not currently not available. Additionally, an effect of short term exposure to salinity may be different from the effects of (semi) permanent exposure, as plants may have difficulty to adapt to changing salinity levels. On the other hand, they also have the opportunity to recover after the salinity peak has past. Some research has been done on exposure of natural vegetation to temporary salinity increase, such as in Australia, there are cases where saline groundwater is discharged into streams that flow through wetlands. Nielsen et al. [2007] assessed the effects on aquatic organisms and Goodman et al. [2010] studied the survival and recovery of the impact aquatic macrophytes after exposure to temporary salinity. Their research showed that these species could regain a positive relative growth rate after recovery.

5 Distribution data and indicator values

5.1 Introduction

Distribution data are the records of species occurrence and abundance in certain areas, and may include information on abiotic conditions. If enough records are available, this type of information can be used to infer relations between abiotic conditions and the occurrence of species. In recent years, distribution data has been used for predictive species distribution modelling, often with the aim of predicting the effect of climate change on species distribution [Guisan & Thuiller, 2005].

Indicator values, such as Ellenberg indicators are numbers assigned to plant species that provide information regarding species distribution over gradients of e.g. moisture, acidity, nutrient availability and salinity [Ellenberg, 1974]. These indicator values are usually assigned on the basis of field observations and expert knowledge. Often the data on plant (or vegetation types) distribution and the indicator values of plants are applied to explore the effects of various factors on the vegetation, using correlation patterns.

Three main sources of information were identified: Ellenberg indicator values [Ellenberg, 1974]; Witte indicator values [Witte et al., 2007], based on ecological species groups [Runhaar et al., 2004], and the data on plants occurrence and ecological indication in SynBioSys [Hennekens et al., 2010]. These three are discussed below. Furthermore, salinity tolerance classifications of plant species have been found in reports by Runhaar et al. [1997] and Runhaar [2006] and a book by Den Held & Den Held [1976]. These classifications are based on occurrence data.

Ellenberg indicator values

Ellenberg indicator values are based on the work of Ellenberg [1974] for the flora of Central Europe. For the Netherlands, indicator values were provided by Stephan Hennekens (Alterra) who maintains the SynBioSys database [Hennekens et al., 2010]. The description of the indicator values as they are used in SynBioSys can be found in Table 3.

Table 3: Descriptions belonging to Ellenberg indicator values, as found in [Hennekens et al., 2010]. These indicator values are not explicitly linked to an objective measure of salinity.

Indicator value	Description
0	Does not tolerate salinity
1	Tolerates salinity
2	Oligohaline
3	Beta – mesohaline
4	Alpha/ beta – mesohaline
5	Alpha - mesohaline
6	Alpha – mesohaline / polyhaline
7	Polyhaline
8	Euhaline
9	Euhaline / hyperhaline

Witte indicator values

Witte et al. [2007] derived plant indicator values from the division of species into ecological groups by Runhaar et al. [2004]. For salinity, this is a rather general classification into value between 1 and 3. A classification in ecological species groups for the Netherlands and Flanders has been proposed by Runhaar et al. [2004]. Regarding salinity, occurrence site types are distinguished as: saline, brackish and fresh sites (these include very fresh and slightly brackish), see Table 4. Species are included in as many groups that are needed to explain 70% of its distribution. This classification is based on 170 000 Dutch vegetation records.

SynBioSys

Another information source is SynBioSys [Hennekens et al., 2010] (http://www.wageningenur.nl/nl/show/SynBioSys-Nederland.htm), which is a database on plant species and vegetation distribution. It is based on the Dutch National Vegetation Database. SynBioSys can be used to plot response curves of species to abiotic conditions based on occurrence and abundance, as found by Schaminée et al. [1995], although the underlying data set is not freely accessible. Salinity can be viewed on the ordinal scale of Ellenberg (described above) or the scale of Wamelink (mg dissolvable chloride per kg soil). Compared to groundwater or surface water concentration, chloride in the soil may not be as strong an indicator as it may be more influenced by temporal fluctuations [Ertsen et al., 1998].

Classification by Runhaar et al. [1997, 2006]

Runhaar et al. [1997] explored the effects of supply of river water to natural areas , using the relationship between plants from aquatic plant communities and different terrestrialization stages of vegetation and salinity. For this study, the distribution data from several databases, including the national database FLORBASE was used. In this study, a more refined classification was proposed: see Table 4. In the report by Runhaar [2006] these salinity classes have been used to assess salinity risk to nature areas.

Table 4: Salinity classifications according to different authors.

<table>
<tr><th>Chloride concentration (mg/L)</th><th>Ecological species groups [Runhaar et al., 2004] used for Witte indicator values</th><th>Classification of plant species to salinity [Runhaar et al., 1997] [Runhaar, 2006]</th><th colspan="3">Classification of fens [Den Held & Den Held 1976]</th></tr>
<tr><td>> 10000</td><td>Saline</td><td>Saline</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>10000</td><td rowspan="4">Brackish</td><td rowspan="4">Brackish</td></tr>
<tr><td>4000</td><td colspan="3" rowspan="2">Brackish fens in North Holland before closure Zuiderzee</td></tr>
<tr><td>2000</td></tr>
<tr><td>1200</td><td colspan="3"></td></tr>
<tr><td>1000</td><td rowspan="2">Slightly brackish</td><td rowspan="2">Slightly brackish</td><td></td><td rowspan="3">Brackish fens North Holland after closure Zuiderzee</td><td rowspan="3">Brackish fens: Botshol</td></tr>
<tr><td>500</td><td rowspan="2">Fresh and oligohaline fens</td></tr>
<tr><td>200</td><td rowspan="2">Very fresh</td><td>Fresh</td></tr>
<tr><td>100</td><td>Very fresh</td><td colspan="3">Fresh water fens</td></tr>
</table>

Den Held & Den Held

In their book about the Nieuwkoopse Plassen, Den Held & Den Held [1976] discuss the distribution of plant species in Dutch fens in relation to salinity (also using the plant occurrence data from the Netherlands). They recognize groups of plant species that show a clear difference in distribution between fens that have different salinity levels (Table 4). The salinity levels they use cannot be interpreted in a strict way, because salinity levels may be subject to both local variations and temporal fluctuations.

5.2 Response of fen species to salinity predicted from ecological indicators

Indicator values of Ellenberg

From the lists of available indicator values (Ellenberg indicator values and Witte indicator values) a selection has been made of species that are tolerant to at least some brackish conditions (Ellenberg indicator value > 0, Witte indicator value > 1). This has been done for all species in the database (of which an indicator value was available) and for a sub-selection of species from fen vegetation. The latter was obtained from SynBioSys by selecting species from typical plant communities defined as 'fresh water fen banks' (which includes different fen terrestrialization stages), see Table 5. About 13 – 18% of fen species with a known indicator value for salinity can be considered to be (slightly) salinity tolerant. All others are primarily associated with fresh water habitats (lowest indicator value for salinity), or have an unknown indicator value.

Table 5: Number of species with indicator values higher than the minimum value.

	Ellenberg indicator value higher than 0, out of all species that have an indicator value	**Witte indicator value higher than 1, out of all species that have an indicator value**
Species from all habitats	14 % (229 out of 1611 species)	9 % (164 out of 1758 species)
Species from fen terrestrialization (395 species)	18% (52 out of 290 species)	13 % (43 out of 330 species)

Relating indicator values with measured salinity

To obtain relevant information from plant indicator values, information about the numerical relation between the indicator value and measured abiotic parameters such as chloride concentrations is needed. Such relations have been established by Ertsen et al. [1998]. They calculated average indicator values for different sites in the Netherlands by averaging the Ellenberg indicator values for all species present. These authors obtained a relationship between the calculated indicator value of each site and chloride concentration of the ground water. However, this relation was weak for low salinity indicator values as there was considerable scatter. This could be caused by the influence of other factors, or by the averaging between Ellenberg values of different species. In the vegetation of fen banks and different terrestrialization stages, various plants differ greatly in their height, but also in rooting depth. As the water quality may differ strongly with depth (e.g. due to shallow rain water lenses) and the salinity gradients within root zones can be steep, plants of different tolerance to salinity can in fact stand next to each other. This makes it difficult to explore the relationship between the vegetation and the abiotic conditions, using the Ellenberg indicator values.

Furthermore, Ertsen et al. [1998] show that plant species with Ellenberg indicator values of 0 and 1 have a slightly lower occurrence above 100 mg/l Cl^- and a steep decrease above 1000 mg/l. This indicates that this group includes species that are sensitive to salinity levels between 100 and 1000 mg/l Cl^-, but also species with higher sensitivity thresholds. For the salinity range that could be expected in fens, the range of this group is too wide to be relevant.

A similar approach has been used by Paulissen et al. [2007a and 2007b] for nature target types (Natuurdoeltypen) of the Netherlands. Ellenberg indicator values of salinity were averaged within vegetation associations of the Netherlands, and converted into units of nature target types. Nature types that are likely to be more sensitive than others were identified, a number of which could be sensitive to concentrations below the current standards. It must be noted that hydrological considerations regarding exposure were not taken into account. These authors mentioned that the response of individual species may be different from the response of the communities in which they occur, due to differences between species. They propose salinity tolerance ranges for a few fen species (*Hamatocaulis vernicosus* and *Liparis loeselii*) within the 'fresh' water range (227 – 321 mg/l Cl^-) [Paulissen et al. 2007].

We attempted to find a relation between indicator values and salinity for individual species, instead of whole vegetation communities. In the KENNAT database [Sanders et al., 2000] a limited number of records were found (namely those for which chloride content of the soil or electrical conductivity of the groundwater was measured). For most species there is not enough data available (indicator value is unknown, salinity level at site is unknown or both are unknown). For none of the plant species, more than 2 records are available, which makes this analysis statistically weak. The results resulting showed no visible relation between salinity indicator value and measured salinity (data not showed). This lack of relationship is most likely due to the limited availability of vegetation records that include (a comparable) measurements of salinity. Furthermore, there is a strong bias in data as there is a large number of records from a fresh water sites (and a number of species that become associated with fresh water conditions and they occur only there) and a limited number of sites in the Netherlands with brackish or saline conditions.

SynBioSys

From the SynBioSys software package [Hennekens et al., 2010] information from larger databases may be obtained. These databases themselves are not freely accessible, but the resulting graphs regarding species distribution on an Ellenberg or Wamelink scale for indicator values can be obtained. These graphs are shown in Appendix C for species from the landscape type fresh water peat banks (in Dutch: ‘Zoete veenoevers’). The graphs show that most species are found in fresh water areas (indicator value between 0 and 1), while a small number of species have a wider range and can be found (seldom) in areas that are associated with Ellenberg values larger than 1 (indicating tolerance to brackish conditions).

Runhaar

The class to which species are ascribed is based on the maximum salinity level below which 70% of the species occurrences were observed. In Appendix D a list can be found of fen terrestrialization species (from key communities of ‘fresh water peat banks’ as found in SynBioSys [Hennekens et al., 2010] that fit salinity classes 1 and 2 according to Runhaar et al. [1997]. This list includes species that are rarely found in chloride ranges above 200 mg/l and are therefore considered potentially sensitive to salinity. In the report by Runhaar (2006) these salinity classes have been used to assess salinity risk to nature areas. It was proposed that increased concentrations in the range of 100 - 1000 mg/L Cl^- may kill sensitive species within several weeks. However, it is unclear at which level /duration effects will occur. The classification of species within salinity classes differs slightly from Runhaar et al. [1997], a list of potentially sensitive species (class 1 and 2) can be found in Appendix E.

Species that are potentially sensitive to salinity

The data that is discussed above was combined in one table that can be found in Appendix F. For each plant species, an overall score was calculated that indicates to what extent an information from different sources about a species is consistent. For each source that gives an indication that the species may not be salinity tolerant, the score goes up. It should be noted that some of the sources may have used the same information. The resulting list of species that are potentially sensitive to salinity can be used for a focus in further research.

Table 5 presents the list of species that could be sensitive to salinity. All of these species have an Ellenberg indicator value for salinity of '0', occur only in areas that are marked with an Ellenberg indicator value for salinity of less than

'1' [Hennekens et al., 2010], and are linked to fresh water areas in at least one of the following literature sources: Runhaar et al. [1997]; Runhaar [2006]; J. J. Den Held & A. J. Den Held [1976]. One species is an exception: Eleocharis multicaulis has an Ellenberg indicator value of '1', but is mentioned by Runhaar [et al. 1997; 2006] as being sensitive to salinity.

Table 5: Fen plant species that are potentially sensitive to salinity.

Potentially sensitive species
Calla palustris
Eleogiton fluitans (Scirpus fluitans)
Hottonia palustris
Juncus bulbosus
Menyanthes trifoliata
Ranunculus lingua
Equisetum fluviatile
Comarum palustre (Potentilla palustris)
Stratiotes aloides
Carex lasiocarpa
Cicuta virosa
Pilularia globulifera
Sium latifolium
Utricularia intermedia
Utricularia minor
Carex elata
Carex pseudocyperus
Lysimachia thyrsiflora
Nymphaea alba
Peucedanum palustre
Sparganium erectum
Acorus calamus
Carex diandra
Carex rostrata
Eleocharis multicaulis
Juncus acutiflorus
Myosotis scorpioides
Myrica gale
Pinus sylvestris
Thelypteris palustris
Valeriana dioica
Veronica scutellata
Caltha palustris
Carex acutiformis
Carex paniculata
Cladium mariscus
Hydrocharis morsus-ranae
Lathyrus palustris
Nuphar lutea
Stellaria uliginosa
Succisa pratensis
Utricularia vulgaris

5.3 Considerations regarding using distribution data and indicators

- Positive values (occurrence) in distribution data provide more information than negative values (non-occurrence) regarding tolerance to abiotic conditions. If a species is (more often than rarely) found in brackish root zone conditions, it is likely to be tolerant to these conditions. However, the opposite is not true: if a species is never found in brackish conditions, it does not mean that it is intolerant. For example, it may have been outcompeted by other species, or it simply never dispersed to brackish areas after it became locally extinct.

- For (semi) terrestrial nature, more vegetation records are found from fresh water habitats than brackish conditions. More determinant habitat conditions (other than salinity) coincide with low salinity levels. For instance: in the Netherlands, species of dry soils are found in fresh environments, simply because the combination of predominantly dry soils and saline conditions does not occur naturally here. Also, environmental gradients may have been narrowed due to water management activities, that focus on keeping most surface water fresh for agricultural purposes. This may result in a perceived tolerance range that is more limited than the actual tolerance range, simply because there are too few vegetation records of brackish habitats available. An example of this is the occurrence range of *Ceratophyllum demersum*: in the Netherlands 90% of the occurrence range is below 500 mg/L Cl^-, while in Finland it is found in salinities up to 3000 mg/L Cl^- and in Mallorca up to 1290 mg/L Cl^- (personal communication J. Veraart, 2013, based on Barendregt et al. [1990]; Luther [1951] and Martinez-Taberner [1988].

- Abiotic conditions are often correlated. Salinity rarely occurs without increased nutrient and sulphate concentrations, and their effects might interact. There is not enough data to separate the effects of correlated abiotic conditions.

- Observations of species occurrence and abiotic conditions are snapshots in time. Temporary fluctuations are not taken into account, and lagging effects of past conditions might be falsely interpreted as effects of current conditions.

- Within databases, methods of observation and measurements sometimes differ between data points: for instance, salinity may be measured in the root zone of the vegetation or in a nearby water body, or it may have been estimated in a qualitative way. Salinity can be measured as chloride content of the water (in mg/L) or the soil (in mg/kg), or it can be measured as electrical conductivity (EC) or total dissolved solids (TDS). This reduces the size of the dataset that can be compared.

6 Experimental studies

6.1 Information regarding response of fen species to increased salinity

Besides observing naturally occurring situations, information regarding salinity tolerance can be obtained through experiments. Most experiments are conducted in controlled environments such as greenhouses or outdoor mesocosm setups. Environmental changes (road salt or waste water contamination) can also be interpreted as experiments as well, although it is more difficult to identify causal relations as correlated factors may be present. Compared to observational data such as discussed in the previous chapter, experiments have the potential advantage that causal dose-impact relationships (including threshold levels) may be derived from them.

Most available literature regarding experiments of salinity tolerance are agricultural studies, that have the objective to maximize yield [Munns & Tester, 2008; Van Bakel et al., 2009]. There is not much literature available regarding experimental studies of salinity tolerance of non-agricultural plant species.

An overview of the literature regarding experimental work on non-agricultural species is presented in Table 6. The information is not fully comparable as different authors use different measures for salinity. For mass concentration units like mg/l or ‰ it is not always clear which salt is meant (NaCl or only Cl^- or a combination with different salts). If no clear unit is mentioned, we assume that the unit is NaCl concentration.

Very little of this information directly applicable to the different terrestrialization stages of Dutch fens. The study of [Hootsmans & Wiegman, 1998] included species that are also found in Dutch fens: *Typha latifolia*, *Phragmites australis* and *Scirpus lacustris ssp. lacustris* (nowadays usually named *Schoenoplectus lacustris*). The authors found that permanent salinity levels of 1.8‰ (estimated ± 1100 mg/L Cl^-) resulted in less aboveground biomass and that *T. latifolia* and *S. lacustris* did not survive permanent salinity levels of 18‰ (estimated ± 11 000 mg/L Cl^-). All species (except *T. latifolia*) did recover from temporary exposure to increased salinity levels. These species are known to occur in (slightly) brackish areas as well as fresh water habitats and have an Ellenberg indicator value of ‘1’.

Howard & Mendelssohn [1999] included *Eleocharis palustris* in their greenhouse experiment, which is a species that occurs in Dutch fens. Their results showed a decrease in biomass with increased salinity, at the lowest salinity treatment of 3640 mg Cl^-/L. Results were measurable at the first harvest, which took place after one month. The steps between treatments are too large to extrapolate to Dutch scenarios. Furthermore, it should be noted that salinity tolerance can differ within species due to genetic differences [Howard, 2009], which means that this species' salinity tolerance may be different in the Netherlands.

Other studies (listed in Table 6) include species that do not occur in Dutch fens, but may provide some insight in potential effects on wild plants. The investigated plant species seem to be affected by salinity levels below 10 000 mg/l Cl^-. Species from naturally (oligo) haline environments are generally tested for higher salinity levels than the species from fresh water environments. A clear effect on fresh water species in these studies is likely to occur in salinity ranges below 4000 - 5000 mg/l Cl^-. However, the effects of addition of slightly brackish water (salt concentrations between 100 and 1000 mg/l Cl^-) are poorly investigated. One study [Van den Brink & Van der Velde, 1993] showed that chloride concentrations as low as 250 mg/L can cause reduced growth in aquatic plants.

Furthermore, the studies that included duration of exposure as a factor show that temporary exposure to salinity may have different effects from permanent exposure, as plant species may show recovery. Two studies addressed the effects of salinity changes in fens in the USA. In both fens the vegetation changed over time, relatively sensitive species were replaced by more tolerant species.

In general, in these studies a clear shifts in the vegetation was observed or was expected to occur under the concentrations of the orders of magnitude of 100 - 1000 – 10 000 mg/l Cl. Often an increasing salinity results in a decrease of biomass of less tolerant species. In the studies found in the literature, the hydrology of the system and the specific transport of salts of brackish water as well as the specific mechanisms of plant responses were not known and not investigated.

It is difficult to extrapolate the outcomes of the experimental studies from the literature to the Dutch situation, for two main reasons:

- The foreign studies were all carried out outside Europe and usually took place under climatic and hydrological conditions different from those in Dutch fens.

- In most cases, different species have been used which do not occur in the Netherlands.

Table 6: Overview of literature of experimental work regarding salinity tolerance of plant species.

Type of species or habitat	**Area of interest**	**Salinity range tested**	**Estimated Cl- [mg/L]**	**Temporary or permanent**	**Salinity sensitivity observed**	**Reference**
The Netherlands						
Common helophytes	Volkerak Zoommeer	1.8 ‰ S – 18‰S	1100 - 11000	Both	Varied among species: growth reduction, mortality, increased growth during recovery	[Hootsmans & Wiegman, 1998]
Aquatic macrophytes	Lower river Rhine and floodplains	1,4 – 7 mmol/L	50 - 250	Permanent	Potamogeton species growth reduced, other not affected.	[Van den Brink & Van der Velde, 1993]
Outside the Netherlands						
Wetland species (germination)	Australia: South eastern Australia	<300 – 5000 mg/l	180 - 3050	Permanent	Varied among species: reduced germination	[Brock et al., 2005]
Freshwater marsh species	USA: Mississippi delta	14 – 15 ‰	8500 - 9100	Temporary	Varied among species: aboveground die-off, recovery, lingering effects	[Flynn et al., 1995]
Fresh/brackish water species	Mexico: lower Colorado river	1.1 – 15 ‰	670 - 9000	Permanent	Constrained growth and reduced transpiration	[Glenn et al., 1995]
Freshwater species	Australia: South Australian wetlands	<1000 – 8000 mg/L	600 - 4850	Temporary	Species can tolerate short term exposure	[Goodman et al., 2010]
Fresh and brackish aquatic species	USA: south-eastern coast	0 – 8 g/kg	0 – 4853	Permanent	Reduced growth for 2 out of 3 species, and changes in competition	[Greiner La Peyre et al., 2001]
Deltaic species	USA: Coastal Louisiana	0 – 6 ‰	0 - 3650	Temporary	Species affected	[Holm & Sasser, 2001]
Oligohaline marsh macrophytes	USA: Gulf of Mexico	6 - 12 g/L	3650 - 7300	Both	Varied among species	(Howard & Mendelssohn 1999)

Freshwater macrophytes	Australia: Victorian wetlands	1000 – 7000 mg/L	600 - 4250	Permanent	Varied among species	[James & Hart, 1993]
Macrophytes	Belize	0.2 – 5 ‰	120 - 3050	Permanent	Varied among species	[Macek & Rejmánková, 2007]
Wetland species (germination)	Australia: Victorian wetlands	1000 – 5000 mg/l	600 – 3050	Temporary	Varied among species	[Nielsen et al., 2007]
Fen plant species	Canada	Up to 569 mg/l Na+	880	Both	Varied among species	[Pouliot et al., 2012]
Oligohaline plant species	USA: Coastal Louisiana	2 – 6 ‰	1200 - 3650	Permanent	Varied among species	[Spalding & Hester, 2007]
Freshwater/brackish wetland species	USA: Gulf of Mexico	Up to 7 µg/g		Permanent	Both positive and negative	[Van Zandt et al., 2003]
Riparian plants	Mexico: lower Colorado river	500 – 4000 mg/l	300 - 2420	Permanent	Varied among species	[Vandersande et al., 2001]
Phragmites australis	China: Yellow river delta	0 – 240 mM	0 - 8500	Permanent	Photosynthesis adversely affected above 60 mM	[Yang et al., 2013]
Change of salinity in ecosystem						
Fen wetland	USA: Illinois	Up to 283 mg/l Cl-	283	Permanent	Vegetation replaced by salt-tolerant species	(Panno et al. 1999)
Calcareaous lake-basin fen	USA: Massachusetts	> 112 mg/l Na+ > 54 mg/l Cl-	54 (higher Na+)	Permanent	Community changes in graminoid fen	[Richburg et al., 2001]

6.2 Considerations regarding use and limitations of experimental studies

- In the field there are many more species than can be studied in an experiment. Even in mesocosm experiments often no more than few species are tested.
- In nature, species grow in competition with each other. This may cause the ecological response of species to differ considerably from its physiological response found in a mono-culture of a pot experiment.

The results of an experimental mesocosm setup with vegetation sods collected from the experiments cannot be, therefore, directly extrapolated to predict the development in nature. However, if the causal relation is found in an experiment, this is a strong argument confirming that a tested factor has a measurable effect on plants.

- Field experiments are difficult to carry out, because often many site-specific factors are co- occurring. Additionally, such experimental treatments can be harmful for vegetation, and therefore usually are not allowed in the protected areas. On the other hand, there are many examples of meaningful small-scale field experiments using enclosures (e.g. Smolders et al. 1995; Van Der Welle et al. 2007).

- Actual root zone exposure is controlled by many factors, including soil type, soil moisture, weather and root architecture. Both in the field and in pot experiments these factors introduce uncertainty regarding exposure. Hydroponic experiments have the advantage that exposure can be controlled, but extrapolation to field conditions remains difficult.

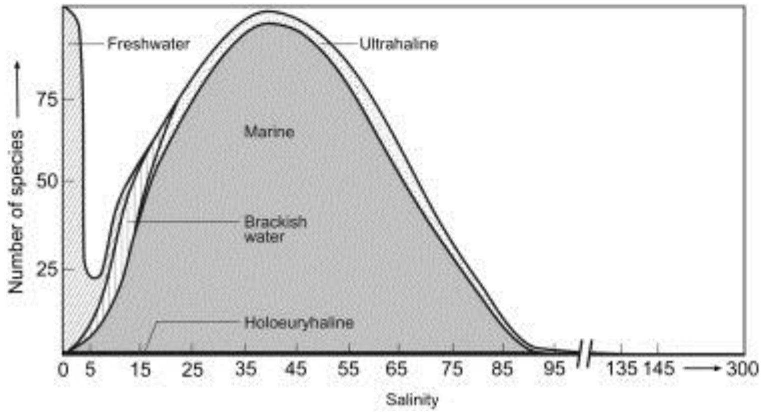
7 Discussion

Salinity tolerance ranges are known for some agricultural species, but are not available for wild plants. Experimental studies on Dutch fen species are mostly unavailable, but studies on foreign species show that tolerance levels can vary widely between plant species, and even at relatively low salinity levels (below 1000 mg Cl^-/L), some plant species can be adversely affected, while others are not. Temporary exposure to salinity may have different effects than permanent exposure, as plant species in the former situation may have the ability to recover.

Distribution data can give insight in the narrowest salinity range in which species can occur, given that reliable data on abiotic conditions are available. Data of measured salinity that can be connected to distribution data is scarcely available, and is complicated by differences in measurement methods. Indicator values provide a general indication and provide some insight in vegetation on a larger spatial scale, but are generally not linked to actual salinity measurements. Connecting them with salinity measurements can be done for ecosystems [Ertsen et al., 1998], but for species this method does not result in clear relationships between indicator value and salinity at sites of occurrence. Both distribution data and indicator values share the limitation that true salinity tolerance may have a wider range, as non-occurrence may be caused by other factors than salinity or salinity ranges may have been narrowed by traditional water management, such as in the Netherlands. Expanding distribution databases with national or international data could improve this.

A small number of plant species from fresh water fen banks are likely to be tolerant to (slightly) brackish conditions, based on their indicator value or their occurrence in brackish conditions. Most fen species are associated with fresh-water conditions. A relatively small group of plants can be marked as potentially sensitive to salinity, as multiple sources mention their non-occurrence in more brackish areas. However, this list may be incomplete and gives no decisive answer regarding true sensitivity. Remane [1934] proposed that fewer fauna species occur in brackish conditions, compared to fresh and saline water (Figure 3). One of the hypotheses explaining this phenomenon is that it is difficult to adapt to changing salinity conditions, as salinity level changes occur more often in brackish habitats than in permanently fresh (habitats above sea level) or saline conditions (sea). The same pattern could apply to plant species, which would mean that if a fresh water fen is exposed to salinity, a drop in species diversity could be observed.

Figure 3: Fauna species diversity under different salinities [Remane, 1934].



Potential sensitivity should not be confused with potential risk, which is a function of both exposure and sensitivity. Exposure may vary strongly between species habitats; some species tend to grow on hydrologically isolated spots (such as rain water lenses), while others are directly exposed to the surface water.

In contrast to using species distribution or experimental data, another approach was suggested by Eallonardo et al. (2013), who attempted to identify traits by which (potentially) salinity tolerant species could be recognized. In a salt marsh in the state of New York (USA), they found that salinity tolerance correlated with elevated N per leaf area and discussed that this trait could be related to ways in which plants tolerate salinity. Data on this trait is, however, unavailable for Dutch fen species in the LEDA Traitbase [Kleyer et al., 2008]. However, this suggests that a shift in species occurrence toward more salinity tolerant species, may result in a change in biomass and litter quality. That could affect other trophic levels (herbivores, decomposition), and therefore affect the whole ecosystem.

Furthermore, besides direct effects on vegetation, salinity may have other effects in fen ecosystems. Salinity influences biogeochemical processes. Van Dijk et al. [2013] show that increased salinity can lead to decreased decomposition and decreased nutrient availability.

8 Conclusion

Similar to agricultural species, fen plant species can be expected to show different responses to salinity exposure. A small number of fen species are known to tolerate brackish conditions. Another group of species is potentially sensitive to chloride concentrations above 100 – 200 mg/L. Distribution data can give limited insight in salinity tolerance ranges of species. Experimental data could provide more insight, but currently few results from experimental studies on naturally occurring species are available.

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Appendices

Appendix A

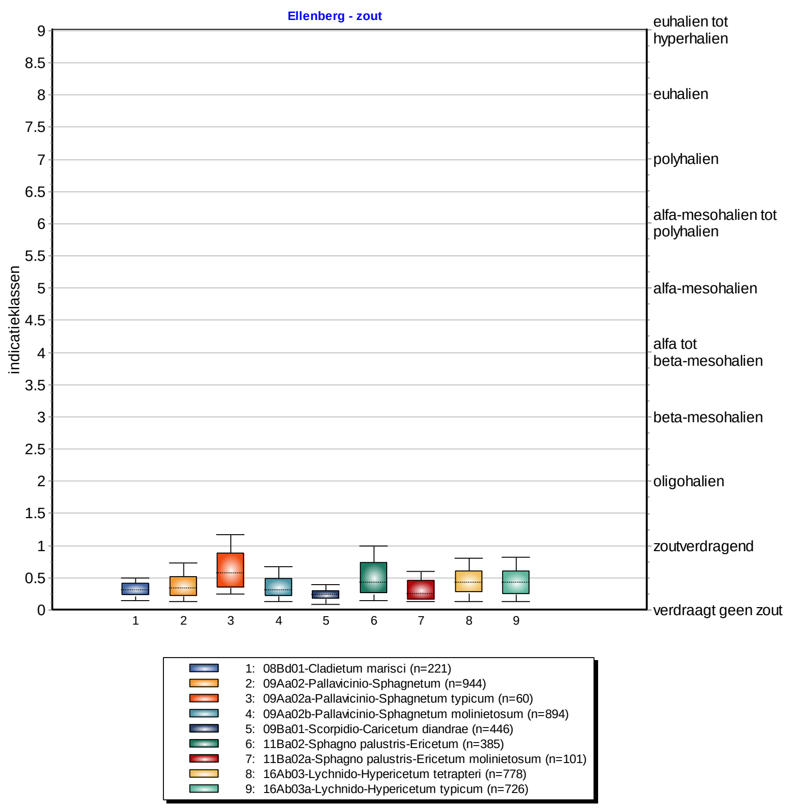
Key communities

In SynBioSys [Hennekens et al., 2010] key communities from the landscape of fresh water peat banks (zoete veenoevers) were selected.

Key communities:

- Cladietum marisci
- Pallavicinio-Sphagnetum
- Pallavicinio-Sphagnetum typicum
- Pallavicinio-Sphagnetum molinietosum
- Scorpidio-Caricetum diandrae
- Sphagno palustris-Ericetum
- Sphagno palustris-Ericetum molinietosum
- Lychnido-Hypericetum tetrapteri
- Lychnido-Hypericetum typicum

Ellenberg salinity indicator for these communities [Hennekens et al., 2010]:



Appendix B

Species in key communities and Ellenberg indicator values

The species lists of the communities in Appendix A have been combined to one list that includes 395 plant and moss species. This list is separated in species that have an Ellenberg indicator value of 1 or higher, and a list of species with an Ellenberg indicator value of 0 or unknown. From moss species the indicator value is not known.

Species number	Species Name	Ellenberg indicator value salinity
683	Juncus gerardi	7
440	Eleocharis uniglumis	5
224	Carex distans	5
1093	Rumex acetosa	4
1135	Samolus valerandi	4
1161	Schoenoplectus tabernaemontani	3
1311	Triglochin palustris	3
870	Oenanthe lachenalii	3
688	Juncus subnodulosus	2
1111	Sagina nodosa	2
514	Festuca arundinacea	2
1112	Sagina procumbens	2
261	Carex oederi s. oederi	2
2143	Chara connivens	2
43	Althaea officinalis	2
1156	Bolboschoenus maritimus	2
933	Phragmites australis	1
66	Anthoxanthum odoratum	1
641	Hydrocotyle vulgaris	1
785	Lythrum salicaria	1
36	Alnus glutinosa	1
959	Poa trivialis	1
1317	Typha angustifolia	1
244	Carex nigra	1
1215	Berula erecta	1
1056	Ranunculus repens	1
673	Juncus articulatus	1
879	Ophioglossum vulgatum	1
248	Carex panicea	1
520	Festuca rubra	1
1048	Ranunculus flammula	1
1369	Vicia cracca	1

1306	Trifolium repens	1
1226	Sonchus palustris	1
723	Lemna minor	1
451	Epilobium hirsutum	1
245	Carex otrubae	1
1006	Potentilla anserina	1
747	Linum catharticum	1
727	Leontodon saxatilis	1
1318	Typha latifolia	1
331	Cirsium arvense	1
2430	Taraxacum sectie Ruderalia	1
1241	Spirodela polyrhiza	1
1949	Schoenoplectus lacustris ag. (incl. S. tabernaemontani)	1
1155	Schoenoplectus lacustris	1
654	Hypochaeris radicata	1
724	Lemna trisulca	1
722	Lemna gibba	1
436	Eleocharis multicaulis	1
2319	Odontites vernus	1
678	Juncus compressus	1

Species number	Species name	Ellenberg indicator value salinity
5	Achillea ptarmica	0
7	Acorus calamus	0
17	Agrostis gigantea	0
18	Agrostis stolonifera	0
19	Agrostis capillaris	0
28	Alisma plantago-aquatica	0
55	Andromeda polifolia	0
60	Angelica sylvestris	0
70	Anthriscus sylvestris	0
135	Bellis perennis	0
139	Betula pubescens	0
140	Betula pendula	0
144	Bidens tripartita	0
153	Briza media	0
173	Calamagrostis canescens	0
174	Calamagrostis epigejos	0
175	Calamagrostis stricta	0
178	Calla palustris	0

186	Calluna vulgaris	0
187	Caltha palustris s. palustris	0
188	Calystegia sepium	0
205	Cardamine pratensis	0
211	Carex acuta	0
212	Carex acutiformis	0
217	Carex buxbaumii	0
219	Carex curta	0
220	Carex oederi s. oedocarpa	0
221	Carex diandra	0
225	Carex disticha	0
228	Carex echinata	0
229	Carex elongata	0
233	Carex flava	0
236	Carex hostiana	0
237	Carex elata	0
239	Carex lasiocarpa	0
249	Carex paniculata	0
254	Carex pseudocyperus	0
255	Carex pulicaris	0
259	Carex riparia	0
260	Carex rostrata	0
262	Carex spicata	0
267	Carex vesicaria	0
296	Cerastium fontanum s. vulgare	0
326	Cicuta virosa	0
332	Cirsium dissectum	0
335	Cirsium palustre	0
337	Cladium mariscus	0
346	Potentilla palustris	0
386	Cynosurus cristatus	0
390	Dactylis glomerata	0
397	Deschampsia cespitosa	0
417	Drosera intermedia	0
418	Drosera rotundifolia	0
419	Dryopteris dilatata	0
420	Dryopteris cristata	0
426	Dryopteris carthusiana	0
427	Thelypteris palustris	0
437	Eleocharis palustris	0
446	Elytrigia repens	0
447	Empetrum nigrum	0
450	Chamerion angustifolium	0
456	Epilobium palustre	0

457	Epilobium parviflorum	0
461	Epipactis palustris	0
462	Equisetum arvense	0
463	Equisetum fluviatile	0
466	Equisetum palustre	0
473	Erica tetralix	0
476	Eriophorum angustifolium	0
477	Eriophorum gracile	0
479	Eriophorum vaginatum	0
490	Eupatorium cannabinum	0
518	Festuca ovina ag. (incl. F. cinerea, F. filiformis)	0
519	Festuca pratensis	0
526	Filipendula ulmaria	0
530	Rhamnus frangula	0
531	Fraxinus excelsior	0
550	Galium mollugo	0
556	Galium uliginosum	0
568	Gentiana pneumonanthe	0
582	Glechoma hederacea	0
584	Glyceria fluitans	0
585	Glyceria maxima	0
597	Hammarbya paludosa	0
618	Hieracium laevigatum	0
626	Hierochloe odorata	0
631	Holcus lanatus	0
638	Hottonia palustris	0
640	Hydrocharis morsus-ranae	0
647	Hypericum dubium	0
651	Hypericum tetrapterum	0
665	Iris pseudacorus	0
670	Juncus acutiflorus	0
679	Juncus conglomeratus	0
680	Juncus effusus	0
714	Lathyrus palustris	0
715	Lathyrus pratensis	0
725	Leontodon autumnalis	0
748	Liparis loeselii	0
759	Lonicera periclymenum	0
763	Lotus pedunculatus	0
766	Luzula campestris	0
768	Luzula multiflora s. multiflora	0
772	Lychnis flos-cuculi	0
780	Lycopus europaeus	0
782	Lysimachia nummularia	0

783	Lysimachia thyrsiflora	0
784	Lysimachia vulgaris	0
813	Mentha aquatica	0
821	Menyanthes trifoliata	0
832	Molinia caerulea	0
841	Myosotis laxa s. cespitosa	0
844	Myosotis scorpioides	0
849	Myrica gale	0
859	Rorippa microphylla	
865	Nuphar lutea	0
866	Nymphaea alba	0
869	Oenanthe fistulosa	0
884	Dactylorhiza incarnata	0
886	Dactylorhiza majalis s. majalis	0
889	Orchis morio	0
890	Dactylorhiza majalis s. praetermissa	0
908	Osmunda regalis	0
912	Oxycoccus macrocarpos	0
913	Oxycoccus palustris	0
921	Parnassia palustris	0
923	Pedicularis palustris	0
929	Peucedanum palustre	0
930	Phalaris arundinacea	0
939	Pilularia globulifera	0
943	Pinus sylvestris	0
946	Plantago lanceolata	0
950	Platanthera bifolia	0
957	Poa palustris	0
958	Poa pratensis	0
967	Persicaria amphibia	0
972	Persicaria hydropiper	0
1005	Potentilla anglica	0
1008	Potentilla erecta	0
1017	Prunella vulgaris	0
1022	Pteridium aquilinum	0
1029	Pulicaria dysenterica	0
1037	Quercus robur	0
1040	Ranunculus acris	0
1047	Ranunculus ficaria s. bulbilifer	0
1051	Ranunculus lingua	0
1066	Rhinanthus angustifolius	0
1074	Rorippa amphibia	0
1089	Rubus caesius	0
1097	Rumex conglomeratus	0

1098	Rumex crispus	0
1099	Rumex hydrolapathum	0
1102	Rumex palustris	0
1117	Salix aurita	0
1118	Salix caprea	0
1119	Salix cinerea	0
1122	Salix pentandra	0
1124	Salix repens	0
1137	Sanguisorba officinalis	0
1154	Eleogiton fluitans	0
1173	Scutellaria galericulata	0
1183	Senecio aquaticus	0
1189	Senecio paludosus	0
1199	Danthonia decumbens	0
1216	Sium latifolium	0
1218	Solanum dulcamara	0
1227	Sorbus aucuparia	0
1229	Sparganium erectum	0
1245	Stachys palustris	0
1247	Stellaria uliginosa	0
1254	Stellaria palustris	0
1255	Stratiotes aloides	0
1258	Succisa pratensis	0
1259	Symphytum officinale	0
1265	Taraxacum sectie Palustria	0
1275	Thalictrum flavum	0
1299	Trifolium dubium	0
1305	Trifolium pratense	0
1321	Urtica dioica	0
1323	Utricularia intermedia	0
1324	Utricularia minor	0
1327	Utricularia vulgaris	0
1331	Vaccinium vitis-idaea	0
1332	Valeriana dioica	0
1333	Valeriana officinalis	0
1362	Veronica scutellata	0
1367	Viburnum opulus	0
1385	Viola palustris	0
1474	Festuca filiformis	0
1500	Poa angustifolia	0
1544	Agrostis canina	0
1556	Carex acuta x nigra	0
1564	Dryopteris carthusiana x cristata	
1593	Salix aurita x cinerea	

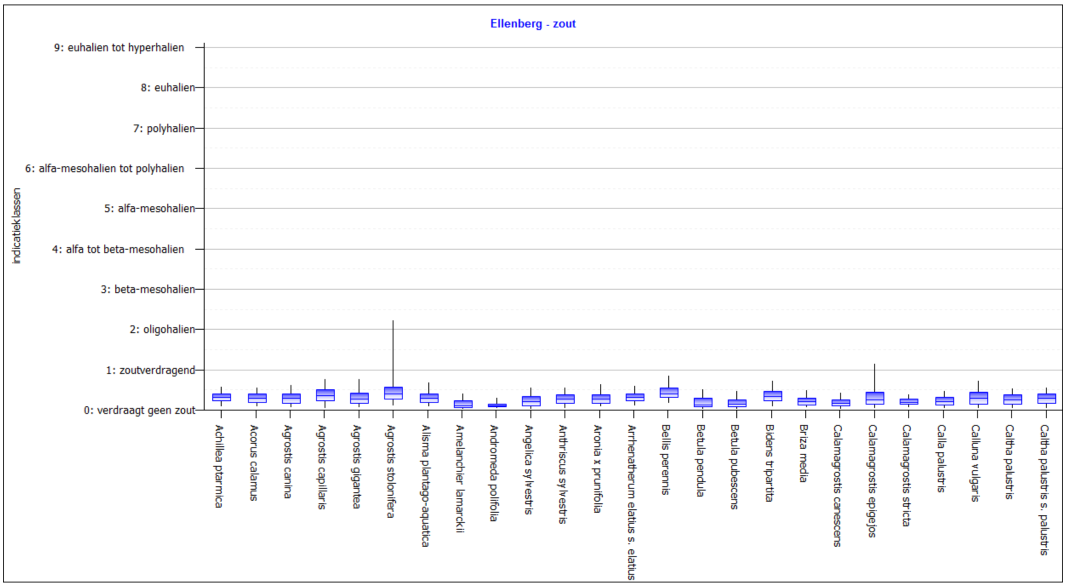
1634	Rubus fruticosus ag.	
1637	Dactylorhiza majalis	0
1642	Epilobium tetragonum	0
1766	Centaurea jacea	0
1852	Amelanchier lamarckii	0
1914	Eleocharis palustris ag. (incl. E. uniglumis)	0
1921	Festuca rubra ag. (incl. F. arenaria)	
1933	Luzula multiflora	0
1965	Aronia x prunifolia	
2131	Zygmales species	0
2153	Chara species	0
2164	Characeae species	0
2314	Cerastium fontanum	0
2316	Euphrasia stricta	0
2320	Plantago major	0
2338	Caltha palustris	0
2343	Juncus bulbosus	0
2373	Typha angustifolia x latifolia	
2376	Galium palustre	0
2391	Arrhenatherum elatius s. elatius	0
5178	Juncus conglomeratus x effusus	
5297	Rubus plicatus	
9340	Salix aurita x caprea	0

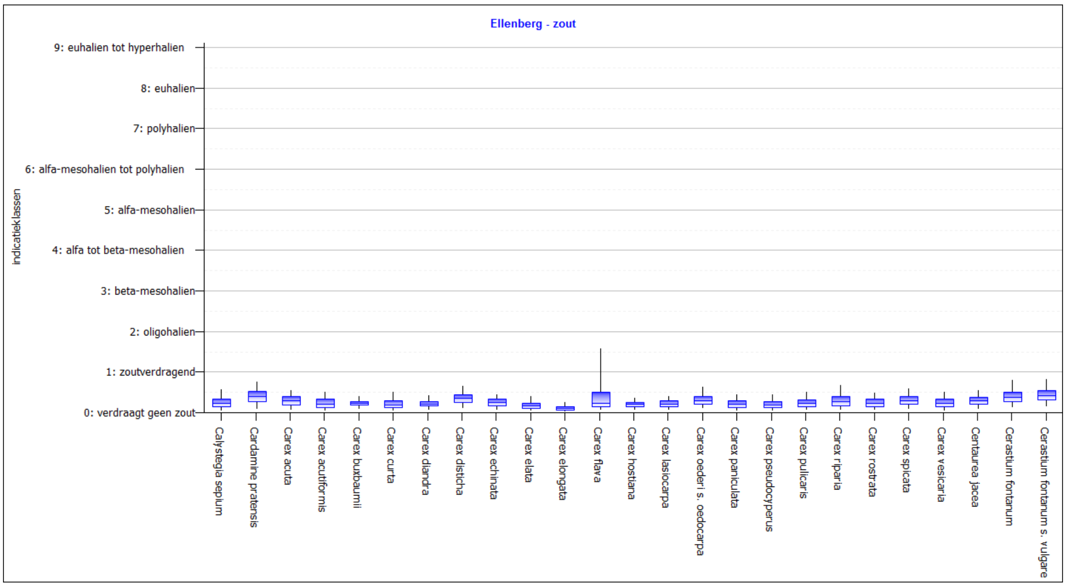
Appendix C

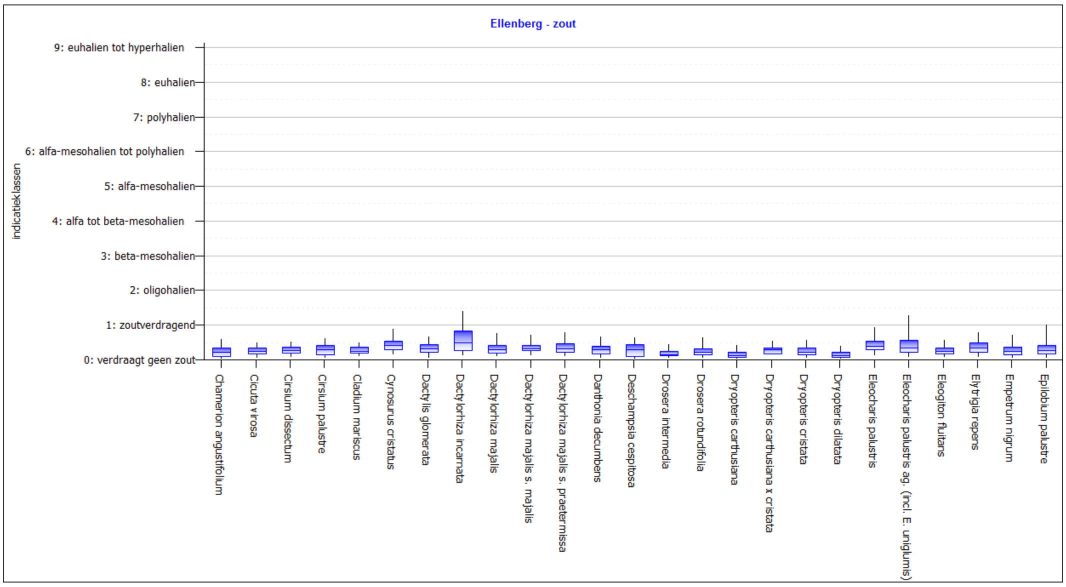
Salinity response based on distribution data

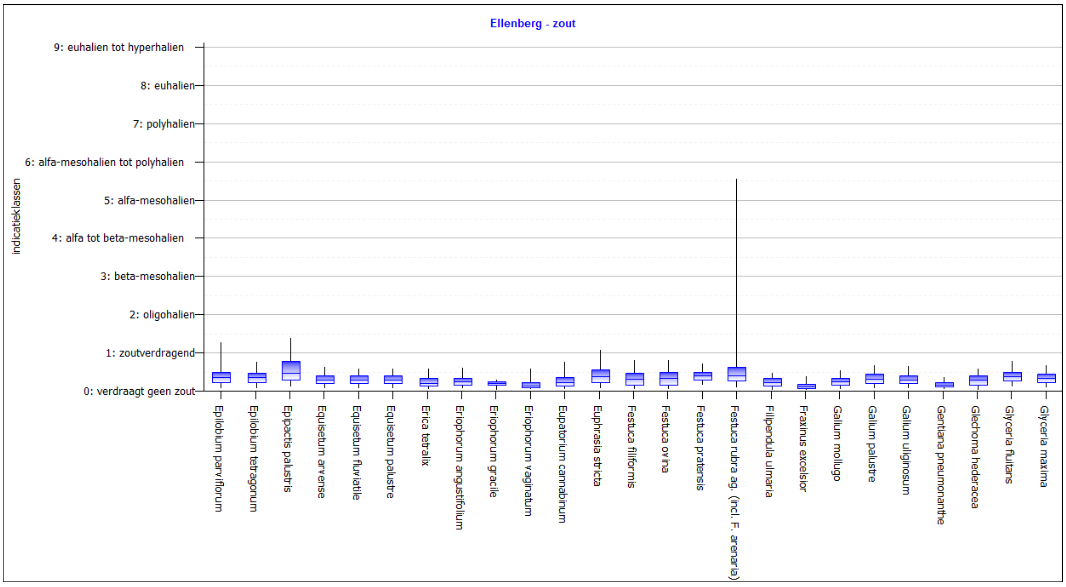
SynBioSys [Hennekens et al., 2010] was be used to create graphs of ecological response of species, based on distribution data as described in 'De vegetatie van Nederland' [Schaminée et al., 1995]. The data is not freely available, but the resulting graphs give a visual overview of the response of species regarding salinity.

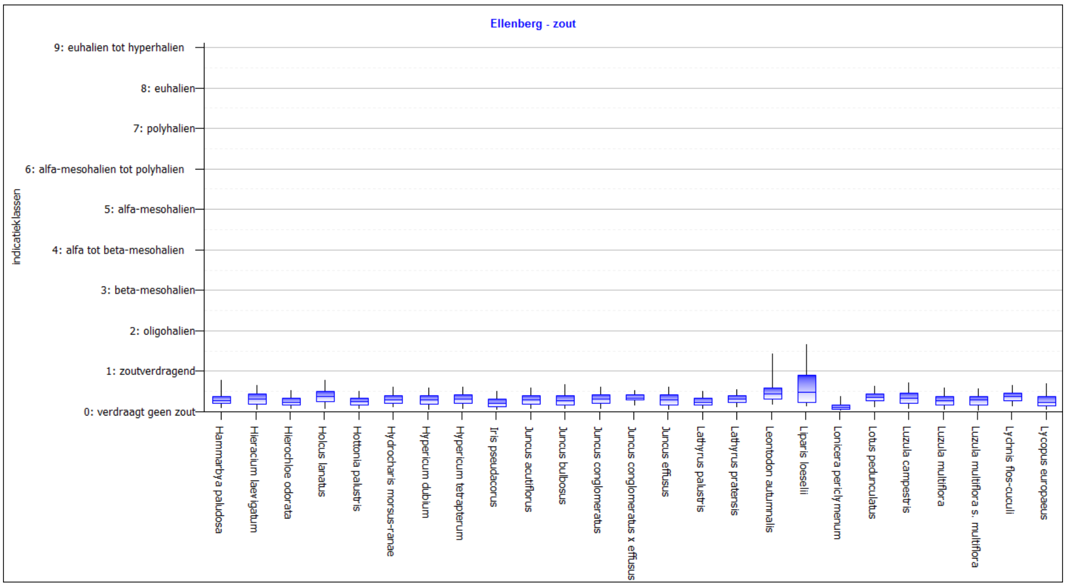
These graphs have been made in SynBioSys [Hennekens et al., 2010] for species that are found in key communities from the landscape type 'Zoete veenoevers' (fresh peat banks). In the graphs of Ellenberg values it is striking that most species occur mostly in fresh sites, and only a few species are (seldom) found in areas that are associated with increased salinity (part of the boxplot reaches above indicator value '1').

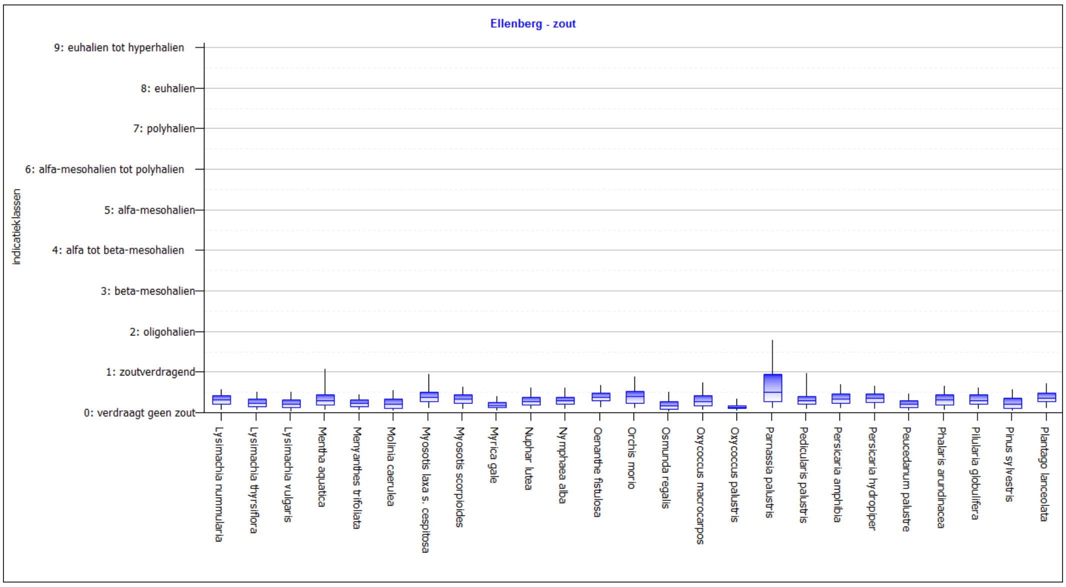


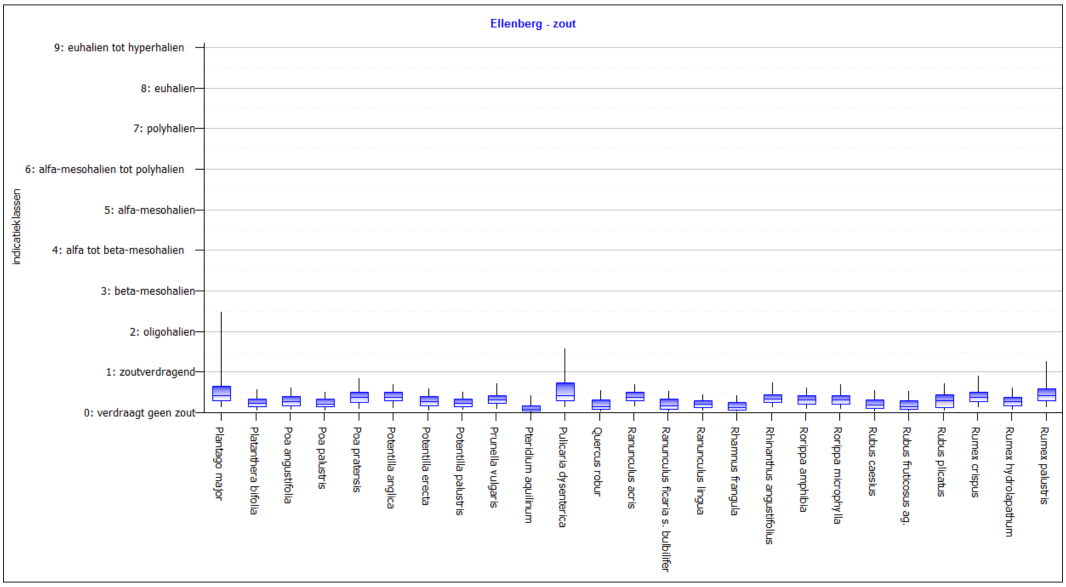

Ellenberg - zout
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
indicatieklassen
Calystegia sepium
Cardamine pratensis
Carex acuta
Carex acutiformis
Carex buxbaumii
Carex curta
Carex diandra
Carex disticha
Carex echinata
Carex elata
Carex elongata
Carex flava
Carex hostiana
Carex lasiocarpa
Carex oederi s. oedocarpa
Carex paniculata
Carex pseudocyperus
Carex pulicaris
Carex riparia
Carex rostrata
Carex spicata
Carex vesicaria
Centaurea jacea
Cerastium fontanum
Cerastium fontanum s. vulgare

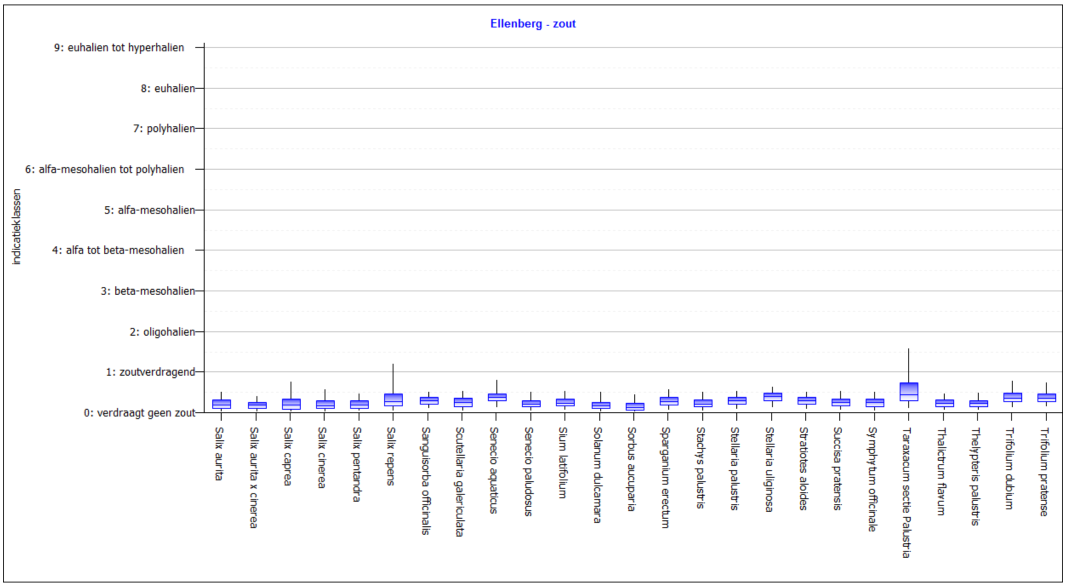

Ellenberg - zout
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
indicatieklassen
Chamerion angustifolium
Cicuta virosa
Cirsium dissectum
Cirsium palustre
Cladium mariscus
Cynosurus cristatus
Dactylis glomerata
Dactylorhiza incarnata
Dactylorhiza majalis
Dactylorhiza majalis s. majalis
Dactylorhiza majalis s. praetermissa
Danthonia decumbens
Deschampsia cespitosa
Drosera intermedia
Drosera rotundifolia
Dryopteris carthusiana
Dryopteris carthusiana x cristata
Dryopteris cristata
Dryopteris dilatata
Eleocharis palustris
Eleocharis palustris ag. (incl. E. uniglumis)
Eleogiton fluitans
Elytrigia repens
Empetrum nigrum
Epilobium palustre

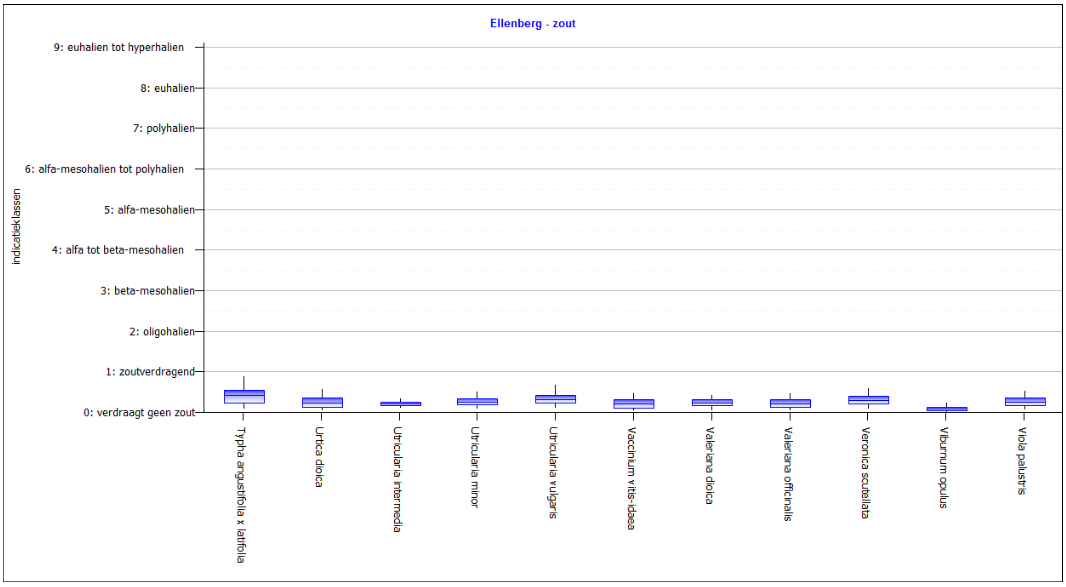

Ellenberg - zout
indicatieklassen
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
Epilobium parviflorum
Epilobium tetragonum
Epipactis palustris
Equisetum arvense
Equisetum fluviatile
Equisetum palustre
Erica tetralix
Eriophorum angustifolium
Eriophorum gracile
Eriophorum vaginatum
Eupatorium cannabinum
Euphrasia stricta
Festuca filiformis
Festuca ovina
Festuca pratensis
Festuca rubra ag. (incl. F. arenaria)
Filipendula ulmaria
Fraxinus excelsior
Galium mollugo
Galium palustre
Galium uliginosum
Gentiana pneumonanthe
Glechoma hederacea
Glyceria fluitans
Glyceria maxima


Ellenberg - zout
indicatieklassen
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
Hammarbya paludosa
Hieracium laevigatum
Hierochloe odorata
Holcus lanatus
Hottonia palustris
Hydrocharis morsus-ranae
Hypericum dubium
Hypericum tetrapterum
Iris pseudacorus
Juncus acutiflorus
Juncus bulbosus
Juncus conglomeratus
Juncus conglomeratus x effusus
Juncus effusus
Lathyrus palustris
Lathyrus pratensis
Leontodon autumnalis
Liparis loeselii
Lonicera periclymenum
Lotus pedunculatus
Luzula campestris
Luzula multiflora
Luzula multiflora s. multiflora
Lychnis flos-cuculi
Lycopus europaeus


Ellenberg - zout
indicatieklassen
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
Lysimachia nummularia
Lysimachia thyrsiflora
Lysimachia vulgaris
Mentha aquatica
Menyanthes trifoliata
Molinia caerulea
Myosotis laxa s. cespitosa
Myosotis scorpioides
Myrica gale
Nuphar lutea
Nymphaea alba
Oenanthe fistulosa
Orchis morio
Osmunda regalis
Oxycoccus macrocarpos
Oxycoccus palustris
Parnassia palustris
Pedicularis palustris
Persicaria amphibia
Persicaria hydropiper
Peucedanum palustre
Phalaris arundinacea
Pilularia globulifera
Pinus sylvestris
Plantago lanceolata


Ellenberg - zout
indicatieklassen
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
Plantago major
Platanthera bifolia
Poa angustifolia
Poa palustris
Poa pratensis
Potentilla anglica
Potentilla erecta
Potentilla palustris
Prunella vulgaris
Pteridium aquilinum
Pulicaria dysenterica
Quercus robur
Ranunculus acris
Ranunculus ficaria s. bulbifer
Ranunculus lingua
Rhamnus frangula
Rhinanthus angustifolius
Rorippa amphibia
Rorippa microphylla
Rubus caesius
Rubus fruticosus ag.
Rubus plicatus
Rumex crispus
Rumex hydrolapathum
Rumex palustris


Ellenberg - zout
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
indicatieklassen
Salix aurita
Salix aurita x cinerea
Salix caprea
Salix cinerea
Salix pentandra
Salix repens
Sanguisorba officinalis
Scutellaria galericulata
Senecio aquaticus
Senecio paludosus
Sium latifolium
Solanum dulcamara
Sorbus aucuparia
Sparganium erectum
Stachys palustris
Stellaria palustris
Stellaria uliginosa
Stratiotes aloides
Succisa pratensis
Symphytum officinale
Taraxacum sectie Palustria
Thalictrum flavum
Thelypteris palustris
Trifolium dubium
Trifolium pratense


Ellenberg - zout
9: euhalien tot hyperhalien
8: euhalien
7: polyhalien
6: alfa-mesohalien tot polyhalien
5: alfa-mesohalien
4: alfa tot beta-mesohalien
3: beta-mesohalien
2: oligohalien
1: zoutverdragend
0: verdraagt geen zout
indicatieklassen
Typha angustifolia x latifolia
Urtica dioica
Utricularia intermedia
Utricularia minor
Utricularia vulgaris
Vaccinium vitis-idaea
Valeriana dioica
Valeriana officinalis
Veronica scutellata
Viburnum opulus
Viola palustris

Appendix D

Salinity class of fen species

Salinity class according to [Runhaar et al., 1997] of fen terrestrialization species (as found in key communities for 'fresh water peat banks' in SynBioSys [Hennekens et al., 2010]. This selection shows a list of fen terrestrialization species that have salinity class 1 (up to 100 mg/l Cl-) or 2 (up to 200 mg/l Cl-). Species that are not included in this list may have a higher salinity class or may not have been assigned a class.

Species	Salinity class
Calla palustris	1
Carex lasiocarpa	1
Carex rostrata	1
Eleocharis multicaulis	1
Scirpus fluitans	1
Hottonia palustris	1
Juncus bulbosus	1
Menyanthes trifoliata	1
Pilularia globulifera	1
Potentilla palustris	1
Utricularia intermedia	1
Acorus calamus	2
Carex elata	2
Carex pseudocyperus	2
Cicuta virosa	2
Equisetum fluviatile	2
Lysimachia thyrsiflora	2
Peucedanum palustre	2
Ranunculus lingua	2
Sium latifolium	2
Stratiotes aloides	2

Appendix E

Potentially sensitive species

List of species from fresh water environments that are considered to have low salinity tolerance or an unknown tolerance as they are only found in fresh water [Runhaar, 2006].

Species
Calla palustris
Cicuta virosa
Eleocharis multicaulis
Scirpus fluitans
Equisetum fluviatile
Hottonia palustris
Juncus bulbosus
Menyanthes trifoliata
Nymphaea alba
Pilularia globulifera
Potentilla palustris
Ranunculus lingua
Sium latifolium
Sparganium erectum
Stratiotes aloides
Thelypteris palustris
Utricularia intermedia
Utricularia minor
Veronica scutellata

Appendix F

Combination of data

Information from several sources is combined to produce an overall score:

1. Ellenberg Indicator value for salinity.
   If indicator value = 0, total score +1
2. Occurrence in areas that are marked with Ellenberg salinity indicator.
   If indicator value < 1: total score +1.
3. Species that occur at chloride concentrations of < 200 mg/l [Runhaar et al., 1997].
   If in list: total score +1.
4. Species that are potentially sensitive to salinity [Runhaar, 2006].
   If in list: total score +1.
5. Species that occur in (mostly) fresh water areas [Den Held & Den Held, 1976].
   If in fresh water: total score +1,
   If in mostly fresh: total score + 0.5.

Species name	Ellenberg indicator value salinity 0 = indicator value > 1 1 = indicator value 0	SynBioSys 0 = Distribution in areas with Ellenberg value > 1 1 = Distribution in areas with Ellenberg value < 1	Runhaar et al. 1997 1 < 100 mg/L Cl- or < 200 mg/L Cl-	Runhaar 2006 1 = 'potentially sensitive	Den Held, 1976. 1 = < 100 mg/L Cl- 0.5 = < 500 mg/L Cl-	Total score
Calla palustris	1	1	1	1	1	5
Eleogiton fluitans (scirpus fluitans)	1	1	1	1	1	5
Hottonia palustris	1	1	1	1	1	5
Juncus bulbosus	1	1	1	1	1	5
Menyanthes trifoliata	1	1	1	1	1	5
Ranunculus lingua	1	1	1	1	1	5
Equisetum fluviatile	1	1	1	1	0.5	4.5
Potentilla palustris / Comarum palustre	1	1	1	1	0.5	4.5

Stratiotes aloides	1	1	1	1	0.5	4.5
Carex lasiocarpa	1	1	1	0	1	4
Cicuta virosa	1	1	1	1	0	4
Pilularia globulifera	1	1	1	1	0	4
Sium latifolium	1	1	1	1	0	4
Utricularia intermedia	1	1	1	1	0	4
Utricularia minor	1	1	0	1	1	4
Carex elata	1	1	1	0	0.5	3.5
Carex pseudocyperus	1	1	1	0	0.5	3.5
Lysimachia thyrsiflora	1	1	1	0	0.5	3.5
Nymphaea alba	1	1	0	1	0.5	3.5
Peucedanum palustre	1	1	1	0	0.5	3.5
Sparganium erectum	1	1	0	1	0.5	3.5
Acorus calamus	1	1	1	0	0	3
Carex diandra	1	1	0	0	1	3
Carex rostrata	1	1	1	0	0	3
Eleocharis multicaulis	0	1	1	1	0	3
Juncus acutiflorus	1	1	0	0	1	3
Myosotis scorpioides	1	1	0	0	1	3
Myrica gale	1	1	0	0	1	3
Pinus sylvestris	1	1	1	0	0	3
Thelypteris palustris	1	1	0	1	0	3
Valeriana dioica	1	1	0	0	1	3
Veronica scutellata	1	1	0	1	0	3
Caltha palustris	1	1	0	0	0.5	2.5
Carex acutiformis	1	1	0	0	0.5	2.5
Carex paniculata	1	1	0	0	0.5	2.5
Cladium mariscus	1	1	0	0	0.5	2.5
Hydrocharis morsus-ranae	1	1	0	0	0.5	2.5
Lathyrus palustris	1	1	0	0	0.5	2.5
Nuphar lutea	1	1	0	0	0.5	2.5
Stellaria uliginosa	1	1	0	0	0.5	2.5
Succisa pratensis	1	1	0	0	0.5	2.5
Utricularia vulgaris	1	1	0	0	0.5	2.5
Achillea ptarmica	1	1	0	0	0	2
Agrostis canina	1	1	0	0	0	2
Agrostis capillaris	1	1	0	0	0	2
Agrostis gigantea	1	1	0	0	0	2
Alisma plantago-aquatica	1	1	0	0	0	2
Amelanchier	1	1	0	0	0	2

lamarckii						
Andromeda polifolia	1	1	0	0	0	2
Angelica sylvestris	1	1	0	0	0	2
Anthriscus sylvestris	1	1	0	0	0	2
Aronia x prunifolia	1	1	0	0	0	2
Arrhenatherum elatius s. elatius	1	1	0	0	0	2
Bellis perennis	1	1	0	0	0	2
Betula pendula	1	1	0	0	0	2
Betula pubescens	1	1	0	0	0	2
Bidens tripartita	1	1	0	0	0	2
Briza media	1	1	0	0	0	2
Calamagrostis canescens	1	1	0	0	0	2
Calamagrostis stricta	1	1	0	0	0	2
Calluna vulgaris	1	1	0	0	0	2
Caltha palustris s. palustris	1	1	0	0	0	2
Calystegia sepium	1	1	0	0	0	2
Cardamine pratensis	1	1	0	0	0	2
Carex acuta	1	1	0	0	0	2
Carex acuta x nigra	1	1	0	0	0	2
Carex buxbaumii	1	1	0	0	0	2
Carex curta	1	1	0	0	0	2
Carex disticha	1	1	0	0	0	2
Carex echinata	1	1	0	0	0	2
Carex elongata	1	1	0	0	0	2
Carex hostiana	1	1	0	0	0	2
Carex oederi s. oedocarpa	1	1	0	0	0	2
Carex pulicaris	1	1	0	0	0	2
Carex riparia	1	1	0	0	0	2
Carex spicata	1	1	0	0	0	2
Carex vesicaria	1	1	0	0	0	2
Centaurea jacea	1	1	0	0	0	2
Cerastium fontanum	1	1	0	0	0	2
Cerastium fontanum s. vulgare	1	1	0	0	0	2
Chamerion angustifolium	1	1	0	0	0	2
Chara species	1	1	0	0	0	2
Characeae species	1	1	0	0	0	2
Cirsium dissectum	1	1	0	0	0	2
Cirsium palustre	1	1	0	0	0	2
Cynosurus cristatus	1	1	0	0	0	2

Dactylis glomerata	1	1	0	0	0	2
Dactylorhiza majalis	1	1	0	0	0	2
Dactylorhiza majalis s. majalis	1	1	0	0	0	2
Dactylorhiza majalis s. praetermissa	1	1	0	0	0	2
Danthonia decumbens	1	1	0	0	0	2
Deschampsia cespitosa	1	1	0	0	0	2
Drosera intermedia	1	1	0	0	0	2
Drosera rotundifolia	1	1	0	0	0	2
Dryopteris carthusiana	1	1	0	0	0	2
Dryopteris carthusiana x cristata	1	1	0	0	0	2
Dryopteris cristata	1	1	0	0	0	2
Dryopteris dilatata	1	1	0	0	0	2
Eleocharis palustris	1	1	0	0	0	2
Elytrigia repens	1	1	0	0	0	2
Empetrum nigrum	1	1	0	0	0	2
Epilobium palustre	1	1	0	0	0	2
Epilobium tetragonum	1	1	0	0	0	2
Equisetum arvense	1	1	0	0	0	2
Equisetum palustre	1	1	0	0	0	2
Erica tetralix	1	1	0	0	0	2
Eriophorum angustifolium	1	1	0	0	0	2
Eriophorum gracile	1	1	0	0	0	2
Eriophorum vaginatum	1	1	0	0	0	2
Eupatorium cannabinum	1	1	0	0	0	2
Festuca filiformis	1	1	0	0	0	2
Festuca ovina ag. (incl. F. cinerea, F. filiformis)	1	1	0	0	0	2
Festuca pratensis	1	1	0	0	0	2
Filipendula ulmaria	1	1	0	0	0	2
Fraxinus excelsior	1	1	0	0	0	2
Galium mollugo	1	1	0	0	0	2
Galium palustre	1	1	0	0	0	2
Galium uliginosum	1	1	0	0	0	2
Gentiana pneumonanthe	1	1	0	0	0	2
Glechoma hederacea	1	1	0	0	0	2

Glyceria fluitans	1	1	0	0	0	2
Glyceria maxima	1	1	0	0	0	2
Hammarbya paludosa	1	1	0	0	0	2
Hieracium laevigatum	1	1	0	0	0	2
Hierochloe odorata	1	1	0	0	0	2
Holcus lanatus	1	1	0	0	0	2
Hypericum dubium	1	1	0	0	0	2
Hypericum tetrapterum	1	1	0	0	0	2
Iris pseudacorus	1	1	0	0	0	2
Juncus conglomeratus	1	1	0	0	0	2
Juncus conglomeratus x effusus	1	1	0	0	0	2
Juncus effusus	1	1	0	0	0	2
Lathyrus pratensis	1	1	0	0	0	2
Lemna minor	0	1	0	0	1	2
Lonicera periclymenum	1	1	0	0	0	2
Lotus pedunculatus	1	1	0	0	0	2
Luzula campestris	1	1	0	0	0	2
Luzula multiflora	1	1	0	0	0	2
Luzula multiflora s. multiflora	1	1	0	0	0	2
Lychnis flos-cuculi	1	1	0	0	0	2
Lycopus europaeus	1	1	0	0	0	2
Lysimachia nummularia	1	1	0	0	0	2
Lysimachia vulgaris	1	1	0	0	0	2
Molinia caerulea	1	1	0	0	0	2
Oenanthe fistulosa	1	1	0	0	0	2
Orchis morio	1	1	0	0	0	2
Osmunda regalis	1	1	0	0	0	2
Oxycoccus macrocarpos	1	1	0	0	0	2
Oxycoccus palustris	1	1	0	0	0	2
Pedicularis palustris	1	1	0	0	0	2
Persicaria amphibia	1	1	0	0	0	2
Persicaria hydropiper	1	1	0	0	0	2
Phalaris arundinacea	1	1	0	0	0	2
Plantago lanceolata	1	1	0	0	0	2
Platanthera bifolia	1	1	0	0	0	2
Poa angustifolia	1	1	0	0	0	2

Poa palustris	1	1	0	0	0	2
Poa pratensis	1	1	0	0	0	2
Potentilla anglica	1	1	0	0	0	2
Potentilla erecta	1	1	0	0	0	2
Prunella vulgaris	1	1	0	0	0	2
Pteridium aquilinum	1	1	0	0	0	2
Quercus robur	1	1	0	0	0	2
Ranunculus acris	1	1	0	0	0	2
Ranunculus ficaria s. bulbilifer	1	1	0	0	0	2
Rhamnus frangula	1	1	0	0	0	2
Rhinanthus angustifolius	1	1	0	0	0	2
Rorippa amphibia	1	1	0	0	0	2
Rorippa microphylla	1	1	0	0	0	2
Rubus caesius	1	1	0	0	0	2
Rubus fruticosus ag.	1	1	0	0	0	2
Rubus plicatus	1	1	0	0	0	2
Rumex conglomeratus	1	1	0	0	0	2
Rumex crispus	1	1	0	0	0	2
Rumex hydrolapathum	1	1	0	0	0	2
Salix aurita	1	1	0	0	0	2
Salix aurita x caprea	1	1	0	0	0	2
Salix aurita x cinerea	1	1	0	0	0	2
Salix caprea	1	1	0	0	0	2
Salix cinerea	1	1	0	0	0	2
Salix pentandra	1	1	0	0	0	2
Sanguisorba officinalis	1	1	0	0	0	2
Scutellaria galericulata	1	1	0	0	0	2
Senecio aquaticus	1	1	0	0	0	2
Senecio paludosus	1	1	0	0	0	2
Solanum dulcamara	1	1	0	0	0	2
Sorbus aucuparia	1	1	0	0	0	2
Stachys palustris	1	1	0	0	0	2
Stellaria palustris	1	1	0	0	0	2
Symphytum officinale	1	1	0	0	0	2
Thalictrum flavum	1	1	0	0	0	2
Trifolium dubium	1	1	0	0	0	2
Trifolium pratense	1	1	0	0	0	2
Typha angustifolia x latifolia	1	1	0	0	0	2
Urtica dioica	1	1	0	0	0	2

Vaccinium vitis-idaea	1	1	0	0	0	2
Valeriana officinalis	1	1	0	0	0	2
Viburnum opulus	1	1	0	0	0	2
Viola palustris	1	1	0	0	0	2
Zygmales species	1	1	0	0	0	2
Liparis loeselii	1	0	0	0	0.5	1.5
Salix repens	1	0	0	0	0.5	1.5
Schoenoplectus lacustris	0	1	0	0	0.5	1.5
Agrostis stolonifera	1	0	0	0	0	1
Calamagrostis epigejos	1	0	0	0	0	1
Carex flava	1	0	0	0	0	1
Dactylorhiza incarnata	1	0	0	0	0	1
Eleocharis palustris ag. (incl. E. uniglumis)	1	0	0	0	0	1
Epilobium parviflorum	1	0	0	0	0	1
Epipactis palustris	1	0	0	0	0	1
Euphrasia stricta	1	0	0	0	0	1
Festuca rubra ag. (incl. F. arenaria)	1	0	0	0	0	1
Leontodon autumnalis	1	0	0	0	0	1
Mentha aquatica	1	0	0	0	0	1
Myosotis laxa s. cespitosa	1	0	0	0	0	1
Parnassia palustris	1	0	0	0	0	1
Plantago major	1	0	0	0	0	1
Pulicaria dysenterica	1	0	0	0	0	1
Rumex palustris	1	0	0	0	0	1
Taraxacum sectie Palustria	1	0	0	0	0	1

To develop the scientific and applied knowledge required for Climate-proofing the Netherlands and to create a sustainable Knowledge infrastructure for managing climate change

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