# Preserving and adapting functions to limited fresh water supply

**Work package leader: Prof.dr.ir. S.E.A.T.M. van der Zee**

## Content



# 1 Description work package

## 1.1 Problem definition, aim and central research questions

For agriculture/horticulture and nature, adaptation to decreasing fresh water availability is crucial in the growing seasons. Rainfall becomes concentrated in fewer, but heavier showers, the inlet of good quality water from main water courses will be under pressure, while evapotranspirative demand grows. Particularly for coastal provinces, this causes an increasing influence of brackish/saline ground water that upwells or directly enters the water courses. This influences which plants can be grown, at which infrastructural and other costs, whether agri/horticultural production remains sustainable, how nature develops at 'abandoned' agricultural areas, and how nature areas and their protection, restoration, and management costs change. A central issue is how agro/ecosystems react to changing salinity. For this reason, the effects of drought and salinity on rural low lands (see WP2) is investigated regarding (i) whether or not current, severely criticized salt tolerance levels of plants are still appropriate, (ii) identifying both economically and environmentally sustainable interesting saline cultures and their management and (iii) the relationships between plant communities and abiotic conditions along fresh-salt gradients, related to management and restoration of nature areas.

Current salt tolerance functions are strongly criticized and a thorough new scientific basis must be developed, that considers periodic instead of only chronic salt/drought stress. These probably lead to more policy negotiation room, affects salt damage re-imbursement costs, and rationalizes fresh water allocation (e.g. is fresh water used for flushing water courses or irrigating cash crops?). For brackish/saline conditions, where conventional cultures show too large yield depressions, new crops that show economic promise will be identified for different salt levels, soils, spatiotemporal variability (particularly with respect to salt concentrations at seedling emergence) and herbicide use, and opportunities to allocate fresh and brackish water with adjusted pricing policies known in economics. Increasing salinity may pose threats and chances for nature, its management and restoration. To predict nature development directions, a much closer cooperation between the disciplines (e.g. biology/ecology, hydrology) is needed to re-interpret plant community and abiotic site factor relationships, considering that the latter vary strongly in time. This implies detailed monitoring, preferably at different potentially salt affected nature areas) along salt-fresh gradients with zonation of plant communities to appreciate different directions for ecological change and  ways to steer manage that change. If changes are perceived as problematic, options for restoration require such insights.

## 1.2 Interdisciplinarity and coherence between the projects

All three projects have the salt concentration in soil as the most important variable for (i) agricultural/horticultural yields in conventional and saline cultures, and for (ii) biodiversity and species composition of nature areas (which species can or can not compete). In a first phase, an assessment is needed of how to quantify salinity: as salt concentrations are spatiotemporally variable, hence any chosen measure (e.g. mean concentration in the plough layer) may not be at arbitrary location and time (Van Dam et al., PPO Wageningen, 32.340194.00, 2007). This issue is investigated by all three PhD students in close cooperation.

Each project of WP3 requires experimental work on causal soil salinity and plant response relationships. Both theoretically and regarding use of facilities (e.g. continuous monitoring equipment under field conditions, field locations), a close cooperation ascertains optimal synergy and common methodological approaches. Although salinity is the controlling factor, other site factors cannot be ignored (e.g. water availability/wetness, pH, redox conditions, nutrient levels). In agricultural production, they affect the yield, whereas they affect which species are feasible in nature areas. For this reason, the three projects are closely related through the impact of salinity, but focus on different aspects, all related with management. In project 3.1 on salt tolerance, the aim is to assess which plants (both cultures and particularly rare/nature plants) grow if saline pressures increase and how management may deal with the risks of drought/salinity yield depressions. Together with project 3.2 focused on both conventional and saline cultures, the management of poor fresh water availability involves salt reduction, adjustment of crop rotation, and the timing of salinity levels for different crops (many plants can cope with some salinity, where often the germination stage is particularly sensitive).

For nature areas (Project 3.3), where salt acts as a filter that may make certain species poor competitors (e.g. birch), some salinity may protect the integrity of the nature areas, making management less cost intensive. The approach chosen is interdisciplinary, in that it combines in an integrated fashion, soil and water science, plant production and physiological aspects, and needs to be well founded in its regional, management, policy making and economic context, to be of use. The challenge is partly the continuous and intensive dialogue between investigators and stakeholders, for which reason, the definition of questions in the initial phase of the project and the implementation of results is undertaken in WP-6 in close cooperation with stakeholders. In particular projects 3.2 and 3.3 are intended to have a field site experiments, that require geohydrological and soil characterization, in close cooperation with WP-2 and WP-6. Innovative of all three projects is that new links on pricing of fresh and salt water as an economic tool for water allocation management is given explicit.

## 1.3 Stakeholders

Our stakeholders are those that have responsibilities to protect water resources (e.g. through the EU Water Framework Directive) or nature areas (Natura2000), and water use and management in general at different scales (e.g. provinces Zeeland, Zuid-Holland, Noord-Holland, Flevoland, Friesland). Stakeholders that are particularly involved in ‘Saline’ agriculture are the Dutch coastal provinces Noord Holland and Friesland, companies involved with development of sustainable saline crop cultivation and regional (e.g. LTO Noord) and national institutions (LNV, VenW) dealing with saline agriculture. Sustainable saline agriculture is linked with cultivation of algae, shellfish and fish in the project “Gemengd Zilt Aqua-Agrarisch Bedrijf” (started December 2009, Noord-Holland and Friesland).

Stakeholders such as waterboards (Zeeuwse Eilanden, Hollandse Delta, Delfland, Schieland, Rijnland, Wetterskip Fryslan, see e.g. Hollands Noorderkwartier-Waterbeheersplan 2010-2015), VenW (Nationaal Waterplan, 2009), aim at adaptation of water economics to dry/saline conditions and economic nature protection and development. The projects of WP 3 contribute to technology and economics of e.g. new brackish agriculture, generating new job opportunities and saving considerable fresh water volumes. HOTSPOTS: Interest in the relationship between water quality and ecology was mentioned by HSOV and in particular the effects of dry years, salt concentrations, and fresh water lens functioning (HSRR, HSWZ). Effects on nature, species and restoration after temporal salinity can only be assessed if salt tolerance is well enough known.

Both for nature (salt as a filter for unpopular species) and for agriculture, plant responses need to be known. Poor fresh water availability and its allocation strategy needs to account for the salinity that plants can or can not deal with (HSWZ, HSZD, HSRS). Alternative saline cultures were mentioned explicitly by HSRS, and also for nature in this mainport, management costs can be decreased by salt filtering of species.

# 2 Project 3.1 Developing Climate Proof Dutch Salt Tolerance Response Functions for Crops

**Project leader: Prof.dr.ir. S.E.A.T.M. van der Zee**

## 2.1 Problem definition, aim and central research questions

Salt damage to crops can be due to reduced water availability due to osmotic effects, selective toxicity or deficiency due to unbalanced soil water composition, sodicity, and direct damage to leaves in case of sprinkling. For the assessment of the osmotic effects in the Netherlands, we still use a similar approach as Maas and Hoffman (1977 denoted MH77). It is recognized that the effect of salt damage depends on (nonexhaustively) plant species and crop type, soil type, salt type, and climate. However, the common approach such as MH77 over-simplifies the statistical assessment of the critical salinity that controls the salt damage function, similar to the drought damage using the Feddes function (Feddes et al., 1978). Consequently, the critical salinity and the slope of the MH-Feddes function varies if experimental conditions differ, and when other factors than salt concentration that affect crop yields are not kept constant. For this reason, crop response functions for salinity are not well-constrained. Since the primary effect of salinity on crop performance is often determined with hydroponic cultures, the translation of such data to field conditions can be quite complicated and further limit the applicability of the response functions. For the same reason data measured for e.g. Californian conditions (MH77) are inappropriate for Dutch conditions. Different types of plant species (e.g. mono- vs. dicotyls) deal with salt stress differently, and physiological behavior regarding the osmotic and the toxicity/deficiency effects that is specific for different plant species plays a role. For these reasons, the current database underlying salt damage assessments is flawed, the conceptual approach is biased (e.g. chronic vs periodical salt stress), and overly simplistic to deal with different conditions such as soil type and the timing of salinity levels in the Dutch climate. Aim of this project is to combine soil physical and plant physiological understanding to improve the translation of hydroponic culture data to field scale salt effects, to incorporate environmental aspects (e.g., periodicity of drought and salt stress; a combination of soil and climate/weather) with plant specific aspects (e.g., germination time and plant growth stages; vulnerability to salinity), into the assessment.

**Central Questions are:**

- How should we account for salt tolerance of plants that is useful for agri/horticulture practices?
- How can we relate laboratory assessments to the complexity of field scale conditions?
- How can we integrate spatiotemporal variability of weather, soil and hydrology in a risk/sustainability analysis?

## 2.2 Approach and methodology

The research involves the development of a conceptual model that relates the different factors that are important with regard to salt effects on wild plants and crops. Factors include (i) plant physiological, (ii) soil type, (iii) climate/weather, (iv) salt composition, and (v) management. The conceptual model is needed to synthesize the data obtained through a literature survey of Salt Response Functions (SRF) for different crops, and to serve as a template for deriving new SRF. The physiological factor concerns the species dependent sensitivities related with germination, seedling establishment, and growth stage, leaf burning depending on irrigation method, and specific effects of toxicity and deficiency in the NaCl-dominated Dutch brackish waters. The soil type, and physio-chemical properties such as hydraulic properties, chemical interactions and element cycling, affect the conversion of laboratory and hydroponic data towards field scale effects. This conversion is also affected by the climate/weather properties and their change during the 21st century. In particular, the periodicity of drought and salt stress and the intensity of these stresses during summers are of concern. This is a central aspect of the research, as for Dutch conditions, the combined drought and salt stress is seldom chronic but mostly limited to the summer. This is even the case for so called saline cultures, which may be resistant to salt, but may require low salt concentrations at germination in early spring. The management and the geohydrological conditions are of importance as they may influence the groundwater salinity, groundwater depth, and leaching efficiency of salts in the wetter fall-spring period. The conceptual approach is twofold: the development of SRF and the integration of SRF in ecohydrological modeling, to enable projections of drought and salt stress under changing conditions. The SRF development involves hydroponic experiments that reveal salt effects at different stages and different duration, as well as pot experiments for selected soils. Using the modeling framework SWAP-ORCHESTRA (Kroes & van Dam, 2003, Meeussen, 2004, De Jong van Lier et al., 2008), the SRF are translated to conditions of field situations. This is an essential step in this project, because it concerns of more than just correcting functions derived from hydroponic studies towards those that account for a limited water filled pore space as in soils. As soon as the soil system comes into perspective, also the origin of salts becomes important, as brackish groundwater leads to completely different conditions than brackish water sprinkler irrigation. The type of soil affects the buffering against changes (of salinity, for instance), the distance over which capillary rise of saline water from the groundwater may occur, and the sensitivity to drought. Hence, besides the primary correction from hydroponic to soil based conditions, the SRF need to comprise implicitly also the ambient conditions and management practice, which cause drought and salt effects to be location specific. From climate scenarios from other projects, weather time series will be derived (rainfall intensity and frequency, evapotranspiration demand), with which future drought and salinity risk assessments become feasible. For practical applications, SRF can never be expressed in terms of computer models. Instead, they should be robust and simple, and input data should be well known or routinely measurable. For this reason the long-term risk of crop yield depressions due to drought and salinity is investigated for the Dutch climate, crops, soil types, and geohydrological conditions in an ecohydrological framework (R, Shah et al., 2010, Suweis et al., 2010, van der Zee et al., 2009, Vervoort and van der Zee, 2008, Rodriguez-Iturbe and Porporato, 2004). With regard to geohydrological conditions, a good link with workpackage 2 is required, with regard to crops and management, the stakeholders need to be intensively consulted to investigate boundary conditions and options for changing those. Results will be translated in WP6 into tables that can be used by both the authorities and the farming community.

## 2.3 Scientific deliverables and results

- methodology for developing salt tolerance functions (SRF) that integrates plant physiological, hydrological, soil, management and climate/weather aspects
- parameterization of SRF for different combinations of plant, soil, and weather properties
- ecohydrological modeling of drought and salt stress to crops: a long term, dynamic statistical risk assessment
- framework for assessing salt stress implications for crops and natural vegetations of projects 3.2 and 3.3 of WP3
- SRF in the form of tables (and excel sheets)

## 2.4 Integration of general research questions with hotspot-specific questions

Interest in the relationship between water quality and ecology was mentioned by HSOV and in particular the question of the effects of dry years and salt concentrations and whether fresh water lenses will continue to function well (HSRR, HSWZ) are integral parts of these projects (effects of drought and salinity on land use, and management options). Effects on nature, species and restoration after temporal salinity can only be assessed if SRF are known well enough. Both for nature (salt as a filter for unpopular species) and (as a boundary condition) for agriculture, if continued in the Schiphol area, the salt – plant responses need to be known. The availability of water and its quality, in relation with agriculture/horticulture/saline cultures/nature demands, and the water allocation conditions derived from that, need to account for the salinity that plants can or can not deal with (HSWZ, HSZD, HSRS). In this respect, alternative saline cultures have been mentioned explicitly by HSRS, but in particular with regard to developing nature in this mainport, management costs can be positively affected by salt filtering of species.

## 2.5 Societal deliverables and results

At this moment, the Dutch authorities compensate farmers if salt damage occurs. All parties benefit from improved Salt Response Functions SRF: compensations are given to those really needing it, fresh water can be directed more efficiently to those requiring it. With better SRF, drought and salt damage can be better anticipated and on this basis flushing of surface water can be optimized. Hence, we can improve water use efficiency, but at the same time, farmers are better able to judge the need for interventions in view of salinity hazards and decide whether their planned crops can be grown sustainably in view of costs for fresh water.

In a broader context, the awareness of salinity hazards in (irrigated) agriculture in Southern Europe, and many other arid and semi-arid countries is even more urgent, and understanding developed in this project will be of profound interest to stakeholders abroad, where conditions differ from those of California (Maas Hoffman, 1977).

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## 3 Project 3.2 Adaptation to dry and saline conditions by crop cultivation exploiting brackish water and saving fresh water

**Project leader: Prof.dr. J. Rozema**

### 3.1 Problem definition, aim and central research questions

**Problem definition**

Gradual and irreversible salinization in the Dutch delta due to global climate warming threatens conventional agriculture. Measures to combat salinization require vast amounts of fresh water at high costs. Fresh water from lake IJsselmeer and Markermeer is used to flush salinizing polders and to suppress upward seepage of brackish water. Recently developed national (National Waterplan 2009) and regional (Waterbeheersplan 2010-2015 HHNK, 2009) policy, aims at saving fresh water during periods with increased drought and salinity. This project evaluates the possibilities of agricultural exploitation of brackish (and saline) water by cultivation of suitable crops, without yield and quality losses. As a result, vast amounts of fresh water will be saved, to be used for other purposes.

**Aims**

1. Adaptation to salinization through an integrated study of crop cultivation exploiting brackish water, rather than considering salinity as an adverse factor for conventional agriculture. thereby increasing the availability of fresh water for other purposes (for maintenance of the ground and surface water levels in large areas of the country; for drinking water, industrial use, for conventional fresh water horti- and agriculture)
2. To cultivate various crops under fresh, brackish and saline conditions under field and hydroponic conditions
3. To quantitatively (yield) and qualitatively assess and compare the response of various crops cultivated with fresh, brackish and saline ground and surface water. These salinity- crop response deliverables are developed in cooperation with projects PhD 3.1&2 of (this) WP3.

**Central Research questions**

The response of crops to brackish and saline conditions will be obtained both in field conditions and with hydroponic cultures and based on a combination of these results a crop may be classified as suitable for cultivation under brackish and saline conditions. This classification will also be based on the derived new SRF in the complimentary project in this WP. In some cases the response to salinity found under field conditions is similar to that obtained with hydroponic culture but often discrepancies occur which may relate to irrigation water composition, soil type and weather conditions. For this reason, crop response functions for salinity can very significantly. Since the effect of salinity on crop performance is often determined with hydroponic cultures, the translation of such data to field conditions can be quite complicated.

More generally classification of salt tolerance of crops is based on threshold and slope of the response curve as described by Maas and Hoffman (1977), based on US climate and soil conditions. This classification systems also neglects that seasonal changes of salinity, precipitation and temperature affect crop performance. If we wish to assess which crops are suitable to be cultivated with brackish water, the central questions are:

- How can we conduct and translate experimental research for laboratory and hydroponic cultures to be relevant for field conditions, in view of salinity, precipitation and temperature variability?
- How do ‘saline’ cultures respond to transient exposure to salt, both with regard to duration and with timing (e.g. seedling phase) of that exposure?
- How can saline agriculture as well as screening of the viability of particular cultures be protocolled towards broadly accepted standards?

## 3.2 Approach and methodology

The aim of this project is to combine soil physical and plant physiological understanding to improve the translation of hydroponic culture data to field scale salinity effects. Conditions of hydroponic cultures are kept constant or vary in a controlled way.

In the Noord-Holland field project on the Wadden island of Texel crops will be drip-irrigated with Wadden Sea and brackish water in sandy soil. In Friesland (Westergo region) crops will be drip- irrigated with brackish (ground) water n clayey soil.

Crops to be tested are sugarbeet, and sea beet, Salicornia europaea, Aster tripolium (all dicots); wheat, barley and corn, all monocotyledons.

Through the ongoing or co-financed projects it is feasible, with moderate costs, to establish a significant field based effort, where our intent is to ascertain sufficiently generic understanding and quantification to be relevant for other areas (e.g. with other soils, geo-hydrological conditions, and possibly climates).

The cultivation of crops with brackish water under field conditions builds on the experience acquired during the 2006-2009 period as part of the BSIK Zilte Landbouw project in Noord-Holland. Field conditions in this project will be monitored to allow a comparison with conditions of the hydroponic culture and comprise a.o. salinity of the irrigation water and of the rooting zone, flux of the drip irrigation system, temperature, rainfall intensity and frequency. In the field experiments the effect of a varying germination time of the seed and varying plant growth stages in response to the brackish irrigation water will be analyzed as well as the dependence of crop performance on periodicity of drought and salt stress. Crop parameters to be measured are described in detail in de Vos and Rozema (2009).

By participation in ongoing projects (see D) this agronomic research component is extended towards both environmental and economic sustainability (e.g. profitability).

## 3.3 Scientific deliverables and results

- Salt responses of various ‘saline’ crops to increasing salinity under various soil and weather conditions
- These responses will be co-developed/combined with those developed by PhD 3.1 and 3.3 (this WP) and will be used as input for ecohydrological modeling (conducted mainly by PhD 3.1).
- Assessment of yield, quality and market value of crops cultivated under varying salinities
- Classification of the suitability of various crops for brackish and saline cultivation based on field tests and after application of the new SRF
- Manuals and protocols describing the practice of brackish and saline cultivation of crops

## 3.4 Integration of general research questions with hotspot-specific questions

Recent evaluations (National waterplan, 2009, Ministerie Verkeer en Waterstaat; Waterbeheersplan, Hoogheemraadschap Hollands Noorderkwartier 2009) point towards increasing problems of drought (frequency, duration, intensity) and salinization in the coastal regions. For the period 2010-2015 the national and regional policy will be to reduce use (and costs) of fresh water for flushing saline surface waters. The present project aims at exploiting vast amounts of brackish water for agriculture while maintaining high, profitable yields. The current project is closely linked with successful innovative projects funded by the Provinces of Noord-Holland and Friesland: “Gemengd Zilt Aqua-Agrarisch Bedrijf”, “Zilte Landbouw Texel”, the icon project for the Wadden area, including Noord-Holland, Friesland en Groningen and the project “Standaardisatie Zilte Teelten” (‘Standardizing Saline Cultures’) financed by the Ministery of LNV. In this project, companies cultivating saline crops from South-West Netherlands and the Wadden region cooperate with knowledge institutes (VU and WUR) and the Organisation for Agriculture in Saline Environments (OASE). In addition, Rozema is involved in the project “Zilte teelten op de kaart” coordinated by LTO Noord, an organisation of agricultural companies of nine Dutch provinces north of the river Meuse. This project aims at further developing saline and brackish agricultural economy in the Netherlands.

Hotspots involved with KvK theme 2 do not specifically address saline and brackish cultivations, but certainly aim at a climateproof agriculture, by reducing the unnecessary use of fresh water, so that more is available in dry and saline periods. The current project undoubtedly contributes to saving vast amounts of fresh water, to be used for other purposes such as. drinking water, industrial processes, fresh water agriculture and maintenance of the water table of IJsselmeer and Markermeer and that of the adjacent rural and urban areas.

### 3.5 Societal deliverables and results

The project indicates the possibilities of adaptation of increased salinisation of Dutch coastal regions as a result of sealevel rise, increased drought due to a warming climate, rather than (expensive) combating salinisation. More in particular:

1. The project explores the possibilities of agricultural use of brackish and saline water,
2. It is projected that vast amounts of brackish water can be used for the cultivation of crops, while yield and crop quality do not or only hardly decrease.
3. Use of brackish water for agriculture will save high amounts of fresh water, to be used as drinking water, industrial process water, for specific agricultural and horticultural practices and maintenance of a high water table of of IJsselmeer and Markermeer and in rural and urban areas in the Netherlands.
4. Flushing with fresh water of polders to suppress increasing salinity due to seepage of brackish ground water can be significantly reduced. This will save vast amounts of fresh water and enormous maintenance costs in the water economy of the water boards.

Salinity of ground and surface water varies markedly from brackish conditions to seawater salinity, which requires the evaluation of crops with varying salt tolerances. Brackish water, though, prevails in the Dutch delta and seawater salinity at inland locations is rare. Where nature values prevail and appear to be linked with brackish or saline ground water, a different scientific approach is followed as described in project 3.3 in WP3.

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# 4 Project 3.3 Predicting effects of changing salinity on inland natural systems on the Dutch coastal plain

**Project leader: Prof.dr.ir. S.E.A.T.M. van der Zee**

## 4.1 Problem definition, aim and central research questions

**Problem definition**

There is consensus that climate change will cause more distinct seasonal differences in drought, rainfall, and temperature in the Netherlands. Summer droughts are expected to occur more often and last longer, and rainfall is expected to be concentrated in more intense showers (Beniston et al. 2007, Van den Hurk et al. 2007).

As a result, salinity pressure will very likely increase periodically in many parts of the Dutch coastal plain. In combination with ongoing sea level rise and soil subsidence, this will cause shifts of current fresh-saline gradients in space and time. In the longer term, current freshwater-dependent ecosystems are likely to experience salinity stress or may turn into brackish systems. Attempts to restore and redevelop nature aiming at particular vegetation types will also be affected by salinization, resulting in different outcomes than expected (Harris et al. 2006). While inland brackish natural areas have become rare in the Netherlands due to major sea defense works, increasing salinity may potentially put high-valued freshwater-dependent communities at stake.

Past studies referring to the Dutch situation (e.g., Roelofs 1991, Ertsen et al. 1998) generally have a qualitative and correlative character or focus on specific ions rather than total salinity. Moreover, temporal variability is usually not adequately taken into account. Finally, while surface runoff is generally disregarded and salinization of the root zone by upward seepage is difficult to quantify, both processes are important for establishing adequate hydrological and chemical balances for the root zone of (semi-)terrestrial systems.

Due to limited knowledge of the exact relationships between salt-related abiotic conditions and biodiversity (in particular plant community composition), it is at present difficult to adequately predict salinity-driven changes and damage to ecosystems (Nielsen & Brock 2009).

**Aim**

To quantify relationships between the spatiotemporal dynamics of drought/salinity and vegetation in terms of species, plant traits and species composition.

**Central research questions**

1. Theoretical basis: what are the best variables or properties to quantify salinity responses and damage thresholds?
2. Time series analysis and descriptive field studies: how do plant and vegetation-related variables correlate with spatiotemporal salinity patterns?
3. Mesocosm experiments on plant communities: what are the short-term dose-effect relationships between salinity and vegetation response parameters?

4. Model building and prediction: how can the empirical outcomes be translated into variables for ecological models and how may Dutch natural areas respond to future salinity-related changes?

## 4.2 Approach and methodology

**Theoretical basis (research question 1)**

The variables (both plant and soil variables) that are most appropriate for quantification of the relationship between salinity and vegetation response (e.g. damage thresholds) will be assessed. This relationship can be described at the level of species (presence/absence) or vegetation types (community composition, probability of occurrence of given vegetation types). Another approach is to link salinity to the indicator values of Ellenberg et al. (1991) or of Runhaar et al. (2004) (Ertsen et al. 1998) or to functional plant traits such as leaf Na-content of leaf K-content (TRY database, Cornelissen et al. 2003). An advantage of the latter approach is that it is less susceptible to apparent correlations and selective sampling procedures. As a result, the relationships will be less biased and more robust, and will allow for extrapolations (Witte et al. 2004, McGill et al. 2006). Choices to be made regarding the variables that will be related to each other (e.g. vegetation functional properties with salt concentrations or loads) will obviously have practical implications for the remaining parts of the project. The options mentioned will be addressed on the basis of a literature review and re-analysis of available data sets. The three PhD students in this work package will closely cooperate to select the best suited variable or set of variables.

**Time series analysis (research question 2)**

Time series data can be used to relate abiotic variables to biotic variables. One option is to relate Alterra's Dutch Vegetation Database to biogeochemical data series (cf. Schaminée et al. 2007). This database contains about 500,000 vegetation samples (releves) dating from the 1920s onwards, a period characterized by large-scale transitions from brackish to fresh conditions in several parts of the Netherlands. This analysis may help identifying relationships between vegetation response on the one hand and the selected salinity variables on the other.

To strengthen and fill possible gaps in the outcome of the time series analysis, we envisage gradient-dependent monitoring to empirically assess how biotic variables (plant fitness, traits, and community composition) co-vary along salinity gradients in selected Dutch natural areas.

**Experimental work (research question 3)**

Studying correlative relationships may lead to wrong interpretations in the case of unrecognized cross-correlations or biased sampling. In this project, experimental work will help to minimize this risk. Experiments are needed to define short-term cause and effect relationships between salinity and vegetation response parameters. Part of the experiments will be carried out in a climate room, greenhouse, experimental garden or in the field, respectively. In any case, we envisage using mesocosms plus perhaps individual species as the experimental units. For practical reasons, we will focus on relevant and important (e.g. Natura 2000) communities (see WP6). The biotic response to a realistic concentration gradient and its temporal dynamics will also be studied in the experiments. Possible response variables to be considered include functional characteristics such as biomass, plant fitness and nutrient status, germination and seedling establishment rates, selected functional plant traits, mycorrhizal colonization, and soil microbial activity (Antheunisse et al. 2007, Geurts et al. 2009).

The correlative fieldwork and the experimental work can be elaborated upon in cooperation with WP6 and the two other PhD students of this work package.

**Modelling (research question 4)**

The use of experiments will allow for the development of ecological predictions on short-term plant response to salinity change. The outcomes of the experiments and the other mentioned project elements will be combined in the development of a model (conceptual and possibly mathematical/statistical) aimed at expressing how changes in salinity pressure will affect natural systems.

## 4.3 Scientific deliverables and results

We expect that at least four scientific papers will result from this project, linked to the four central research questions:

1. A theoretical study on quantification of vegetation responses to salinity changes, including assessment of
2. damage thresholds.
3. An overview of changes in plant species composition of natural areas in previously brackish areas of the Netherlands since the first half of the 20th century.
4. Empirical relations of the responses of selected vegetation types to salinity changes and threshold
5. A description and prediction of vegetation responses to salinity changes and threshold exceedance. exceedance.

## 4.4 Integration of general research questions with hotspot-specific questions

Availability of sufficient high quality freshwater to natural areas as well as for other functions during periods of drought is a major and growing concern to hotspot regions on the Dutch coastal plain (e.g. Ondiepe wateren and veenweiden, Haaglanden, Rotterdam, Zuidwestelijke Delta, Schiphol). In view of climate change, the Dutch National Water Plan (2009) aims at regional self-sufficiency with respect to freshwater supply. How scarce freshwater supplies should be distributed is an important question for many hotspot regions and partners. This is important due to biodiversity targets and European regulations (Water Framework Directive, Birds and Habitats Directive). Therefore, for hotspot regions it is important to know which natural areas and which natural communities are present and to what degree they are sensitive to saline water. This knowledge will help them in managing and restoring natural areas and (re)formulating biodiversity targets.

## 4.5 Societal deliverables and results

**Societal relevance**

At present, options to adequately predict the consequences of (periodically) changing salinity levels on inland Natura 2000 sites and other natural areas in the Netherlands are extremely limited. However, there is a clear need for knowledge on this point, since several EU directives impose upon the Dutch authorities the need to protect characteristic communities of their natural areas as well as the ecological and chemical quality of their hydrological infrastructure.

The developed model will allow predictions of how Dutch natural areas will respond to future salinity-related changes. Discharge of the Rhine and other main rivers is expected to decrease in summers. This will increase the salinity of these rivers. In addition, decreasing river discharges will significantly enhance upstream intrusion of seawater. This will limit the possibilities for the traditional supply of surface water from the main rivers (e.g. as near Krimpen a/d IJssel) to freshwater-dependent natural areas during periods of drought. Likewise, as addressed in work package 2, upward seepage of saline groundwater will cause increasing salinity pressure to the Dutch coastal plain. This may cause local extinction of sensitive freshwater-dependent species.

Several peaty lowland or meadowland areas (e.g. Reeuwijkse, Nieuwkoopse, Vinkeveense, Ankeveense Plassen, het Hol, and Ilperveld) are sensitive to changes in salinity of supplied water from outside. However, just how sensitive the natural communities in these areas to increased salt levels is not sufficiently clear.

**Applied aspects**

This project aims at identifying scientifically sound damage thresholds for key natural units and priority areas. Moreover, the project will deliver a model tool allowing managers of water resources and natural areas as well as government bodies to better anticipate future salinity trends and fluctuations and to optimally weigh management options.

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