Monitoring of salt-marsh vegetation by sequential mapping

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Uncertainties in field sampling and vegetation classification

J.A.M. Janssen

4.1. Introduction

In the field sampling uncertainties arise during determination of the sampling scheme and during the acquisition of relevés. In the acquisition of relevés, uncertainties arise in the species capture (the proportion of described species from the total number of species in a plot), in the abundance and cover assessment of species and in the description of other aspects like vegetation structure and management observations, this latter aspect not being discussed here. The field sampling uncertainties affect the description of the relevés and, therefore, the vegetation classification.

Causes of field sampling uncertainties are the spatial and temporal variability and the fuzziness in the vegetation and in the elements on RS-images. Aspects that affect these uncertainties are the number, expertise (skill, experience and training), accurateness and subjectivity of surveyors, the time constraint for making a relevé, the circumstances during field work (weather, insects, etc.), the type of vegetation, the plot size and the phenology of species, depending on the period of the growing season.

Vegetation classification deals with the clustering of relevés into vegetation types. This involves determination of boundaries within a set of relevés and construction of a hierarchy in vegetation types. The boundaries between abstract vegetation types are sometimes gradual (fuzzy) and sometimes discrete (crisp). The determination of a boundary in a gradient situation is always arbitrary. In this thesis the computer algorithm SALT97 (de Jong et al. 1998) is used for a preliminary classification of relevés. The final classification, however, is determined by expert knowledge. The quality of the classification results strongly depends on the (subjective) expertise of the surveyor.

When making a vegetation map for inventory purposes, the quality of the field data should be sufficient to distinguish clusters of similar vegetation relevés (against a background of noise and internal variance). The vegetation classification should give a complete (at the survey scale) and relevant (in relation to the mapping aim) representation in vegetation variation of the study area. When making a map within a monitoring programme, the same vegetation types in relevé sets of different years have to be synthesised. For monitoring a consistent vegetation typology in different years is essential. However, the subjective influence of the surveyor on the final classification causes uncertainty on the consistency of vegetation types of different years.

The research question of this chapter is:

- How large are the effects of sampling uncertainties and classification subjectivity on the vegetation typology?

To answer this question, a field test has been carried out aiming at quantification of the uncertainties in sampling scheme, species capture, abundance assessment, plot size and sampling date and at analysing the effects of these uncertainties on vegetation typology. These
tests are discussed in §4.2. For quantification of vegetation classification uncertainties, a test is carried out in which different surveyors classified a set of relevés. This test is discussed in §4.3.

4.2.  

Field sampling test

4.2.1. Method

A field test has been carried out on 20 September 1996 in the Kwade Hoek, in the southwest of The Netherlands. The study area is a ‘green beach’ according to the definition of salt-marsh types by Westhoff (1985) and consists of salt marshes, dry dunes, dune slacks and many transition zones (Westhoff et al. 1961; van Dort & Severijn 1999). In the study area six groups of two or three field workers made relevés in 8 permanent plots (PQs) of 2 x 2 m² and in 8 photo-elements. The mean expertise with making relevés in similar areas was assessed to be similar in each group. Each group had about four hours for the recording of 16 relevés. For the sampling of elements each group had a photo copy on which an area was marked in which the element had to be sampled. The elements were described in a way that confusion with other photo-elements was negligible. The cover of the plant species within a relevé were estimated according to the decimal scale of Londo (1976): 10% interval classes and below 5% in the classes r, p, a and m of table A.5 in appendix 3. Bryophytes and lichens were not recorded. For each PQ the total number of species found by all groups has been considered as the real number of species occurring in the plot. By an 'expert judgement' it has been determined which species have been identified incorrect and which species have been missed by the different groups. Uncertainty in the abundance estimation has been quantified by calculation of the mean cover and standard deviation per species of the six relevés made in a permanent plot. The cover assessments have been divided into the categories 'simple' and 'difficult', depending on how well they relate to a parameter in which the cover may be estimated (table 4.3). The effect of assessment inaccuracy and choice of plot location and plot size on the vegetation typology has been determined by allocating all relevés to the standard salt-marsh typology SALT97 (de Jong et al. 1998).

<table>
<thead>
<tr>
<th>Assessed cover</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>Simple</td>
</tr>
<tr>
<td>Structure layer</td>
<td>Simple</td>
</tr>
<tr>
<td>Species</td>
<td></td>
</tr>
<tr>
<td>In species-poor vegetation</td>
<td>Simple</td>
</tr>
<tr>
<td>In species-rich vegetation</td>
<td>Simple</td>
</tr>
<tr>
<td>One dominant species</td>
<td>Simple</td>
</tr>
<tr>
<td>Codominant species</td>
<td>Difficult</td>
</tr>
<tr>
<td>Accompanying species</td>
<td>Difficult</td>
</tr>
</tbody>
</table>

Table 4.3. Distinguished types of assessments
4.2.2. Results

Table A.7 in appendix 4 shows the relevés of the permanent plots. Table A.8 in appendix 4 shows the relevés made in the photo-elements. The 5%-interval cover values are transformed to the abundance codes of table A.5 in appendix 3 for computer technical reasons. In the header data in both tables SALT97-codes are shown. Species that are identified incorrectly or which have probably been confused, are shown in a light grey colour in table A.7 in appendix 4. With 14% of all species, recognition or identification problems were encountered, and of all observations 0.7% was erroneous. The following species have never been missed in a permanent plot: *Glaux maritima*, *Agrostis stolonifera*, *Carex distans*, *Pulicaria dysenterica*, *Calamagrostis epigejos*, *Centaurium littorale*, *Potentilla anserina*, *Trifolium pratense*, *Oenanthe lachenalii*, *Mentha aquatica* and *Scirpus cariciformis*. Finally, those species that have been erroneously determined were mostly in a vegetative life stage.

The following results were determined (after correction for incorrect identifications) for all of the PQ data:
- on average 50% of the species in a PQ have been found by all 6 groups;
- on average 68% of the species in a PQ have been found by at least 4 of the 6 groups;
- on average 75% of the species in a PQ have been found.

Table A.7 in appendix 4 demonstrates for each PQ the percentage of occurring species found on average. In general 1 or 2 species were missed in species-poor vegetation and 5 to 6 species in species-rich relevés. Maximally in PQ 16 a group missed 14 species. In the sampling of photo-elements the chosen plot size varied between 4 and 30 m². The relation between plot size and species capture is shown in figure 4.1. Abundance values of dominant species ('simple assessments') are presented in dark grey in tables A.7 and A.8 (appendix 4). For the species found by all field worker groups, the mean and standard deviation for the cover assessment of six observations have been calculated. These are presented in figure 4.2 for the permanent plots and in figure 4.3 for sampling of the photo-elements.

In figure 4.2 and 4.3 the data have been divided into ‘simple assessments’ (■) and ‘difficult assessments’ (○). Simple assessments relate to assessment of overall cover, cover of structure layer, species cover in species-poor vegetation and cover of dominant species (see table 4.3). In both figures an optimum curve has been fitted through zero and the resulting function and regression coefficients have been indicated.

4.2.3. Discussion

Sampling scheme
The field sampling scheme (or sampling design) relates to the location of field plots. It has been shown that both the sampling size and scheme have effect on the classification or ordination of relevés by computer programmes like TWINSPAN and CANOCO (Jongman et al. 1995), as well as on the classification of digital RS-images (Congalton 1988a). In a forest study different methods or intensities of survey caused much larger differences in relevés than did different seasons or observers (Kirby et al. 1986).
Figure 4.1. Relation between plot size and species capture for relevés made by six field work groups in 8 photo-elements (each graph shows the results of 2 photo-elements)

Figure 4.2. Mean and absolute standard deviation (in %, based on observations by 6 surveyors) of simple (■) and difficult (○) cover assessments, with regression lines fitted through zero. The figure shows that the relation between mean and standard deviation is a type of optimum function. The standard deviation is larger for the difficult assessments.
Figure 4.3. Mean and absolute standard deviation (in %, based on observations by 6 surveyors) of simple (•) and difficult (○) assessments for different locations of the same photo-element within a land unit. The regression lines are fitted through zero. Compared to figure 4.2 the standard deviation of the difficult assessments is higher for those values below 40%. The function results in negative standard deviation values for high assessments, due to a lack of data. Therefore, a skewed function will give a better representation of the relation. For the simple assessments the standard deviation is a little higher than in figure 4.2.

Burrough & McDonnell (1998) gave an overview of different sampling schemes. For the Landscape Guided Method Zonneveld (1974a) used stratified random sampling in which the map is stratified by the different land-cover types (the photo-elements). Zonneveld (1974a) stated that simple random sampling is impractical because it is too costly in time and money. Van Genderen et al. (1978), Ginevan (1979), Rudd (1971) and Dicks & Lo (1990) agreed with this point. Lo & Watson (1998) found stratified random sampling to perform best in vegetation mapping of a swampy environment with complex spatial vegetation patterns. Other authors preferred cluster sampling (Rhode 1978) or systematic unaligned sampling (Fitzpatrick-Lins 1978ab). Smartt & Grainger (1974) found that stratified systematic unaligned sampling provided best results in the assessment of the relative proportion of a priori defined vegetation type in a given area. Congalton (1988a) compared different sampling schemes for the evaluation of remote sensing based classifications of agriculture, rangeland and forest areas. He concluded that simple random sampling and stratified random sampling could be used in all situations. Stratified random sampling should be used especially when it is necessary to make sure that small, but important areas are represented in the sample. This method has been readily
accepted as the most appropriate method of sampling in resource studies using remote sensing (van Genderen et al. 1978).

From the test it appeared that different plot locations within a sampled photo-element had little effect on the typology (Table A.8 in appendix 4). Only in the third relevé of element 14 is a different main type allocated (J-type instead of R-type), probably caused by the high cover of *Juncus gerardi* in this relevé. The abundance of this species, which plays a key-role in the typology, varied within the photo-element. The sampled element was likely to be either relatively heterogeneous in species composition or a different element. The assessment of the *Juncus gerardi* cover may also be too high, because, if both *Festuca rubra* and *Juncus gerardi* are present, it is difficult to estimate their cover.

As stratified random sampling provided stable results in the tests and it provides a sample of the complete variation in vegetation in an area, it is concluded that a stratified random sampling scheme is the most appropriate for the mapping methods adopted in this thesis.

**Sampling size**

Ginevan (1979) used the binomial probability function to calculate the optimal sample size needed for specific map accuracy. The number of samples needed for map accuracy assessment, relates to two factors: the number of samples needed to reject a map as being inaccurate and the number of samples required to determine the true accuracy. The probability of accepting a map while it is inaccurate, is called a type II error or producer's risk. The probability of rejecting a correct map is called a type I error or consumer's risk (see §3.4.3).

Considering type I errors, van Genderen & Lock (1977) and van Genderen et al. (1978) calculated that, if only maps with a 95% confidence intervals are accepted, a minimum of 30 samples is required. A larger sample size is needed if also type II errors are considered (Ginevan 1979). Hay (1979) concluded that for an accuracy assessment a sample size of at least 50 pixels per class is needed. With a lower sample size, accuracy results may be biased by chance. Furthermore, the larger the sample size, the smaller the confidence limits of an accuracy value. Finally, Congalton (1988a) found that a sample size of around 1 percent of the area per class is needed to stabilise results, and that for relatively heterogeneous classes (thematic or spectral) an even larger sample size may be needed (Curran & Williamson 1986).

The optimal sample size depends on the spatial resolution of the image compared to the resolution of elements in the field (ground resolution). If the spatial resolution of an image is considerably finer than the ground resolution, then pixels will be highly correlated with their neighbours and inter-pixel variation will be low. If more than one ground element occurs within a sample on an image, intra-pixel variance will be high. In this case the pixel is called a mixed pixel or mixel. As the resolution of ground elements comes closer to the pixel resolution, the likelihood of neighbours being similar decreases and inter-pixel variation becomes high (Skidmore 1999). Woodcock & Strahler (1987) found the highest intra-pixel variation when the spatial resolution was 0.5 to 0.75 of the ground resolution (see also Skidmore 1999).

The results of a test with increasing sample size for image classification are shown in figure 6.4. It indicates that the required sample size for stabilisation of the accuracy and in the maximum accuracy reached, differs between vegetation types. A sample size of about 1200 pixels or 0.4 percent (of the area of the type) was needed for optimal accuracy for both types. However, the clusters consisted of a relatively high number of pixels (about 300 per cluster on average). Congalton (1988b) advised that clusters should be no larger than 10 or
a maximum of 25 pixels in a digital image, for otherwise too small an amount of information is added to a cluster.

No studies on the effect of sample size on photo-interpretation are known from literature. As photo-interpretation takes into account textural and geographical aspects, next to spectral features, field samples for photo-interpretation may be considered as clusters of pixels. If these 'clusters' are considered as having a size of 10 pixels (the advised maximum cluster size by Congalton (1988b)), five samples are needed to achieve the minimal sample size of 50, that is recommended by Hay (1979). Therefore, a sample size of 5 samples per photo-element is considered sufficient, if a photo-element represents just one vegetation type. If a photo-element represents more than one vegetation type or a very heterogeneous vegetation type, it is recommended to extend the sample size during field work. The additional samples should be distinguished from the samples of the stratified random scheme, in order to maintain the consistency of the sampling scheme in time.

Species capture
Several studies showed that the species capture of the same relevé may differ considerably among different observers (Tüxen 1972; Lepš & Hadincová 1992; McCune et al. 1997). Expertise and accurateness of observers is often considered as one of the most important quality aspects of making relevés (Kirby et al. 1986; de Koning 1992; McCune et al. 1997; Rich & Smith 1996).

Basically, a relevé should include all vascular plants and also bryophytes and lichens. In practice usually reliable classification results are obtained with vascular plants only (Krahulec et al. 1986). Dirkse (1998) showed that the absence of bryophytes affected strongly the classification of forest relevés by the clustering algorithm TWINSPAN. For salt-marsh areas the recording of bryophytes is of minor importance for vegetation classification.

In the field tests, the statements that some species are determined incorrectly is based on an ‘expert-judgement’. Therefore, the statements are not absolutely true for the expert-judgement may be incorrect. The species may also hybridise (f.i. *Elymus farctus* and *E. athericus*), so that absolute and certain identification in the field is impossible. The species capture per permanent plot is based on a summation of observations; it may contain incorrect identifications and it is possible for all six groups to have missed species in a given plot.

The number of identified species in a plot varied strongly between the different groups (table A.7 in appendix 4). It is concluded that the factors 'expertise' and 'meticulousness' are important causes for differences in the relevés. The general expertise varied more among the surveyor groups than was expected at the beginning of the tests and this difference was apparently not minimised by working with two or more surveyors. Maybe some relevés were not surveyed meticulously due to the relatively short time (four hours) that was available for the 16 relevés. Nilsson (1992) has advised to increase relevé accuracy by combining the work of two separate investigators, each undertaking independent relevés.

Confused species often were within one genus or closely related genera. Missed species were mostly small, inconspicuous and occurring in low abundance. In species-rich plots a higher number of species were missed, but when considered relatively, the missed number of species in species-rich plots was comparable with the missed number of species in species-poor plots. The plots in which the most species have been missed (PQ2 and 9) contained a dense species-rich forb-vegetation. The other species-rich plots (PQ12, 16 and
7) were grazed and, therefore, likely to be easier to survey. The PQs 6 and 8 are more species poor and open and once again easier to survey.

Table A.7 in appendix 4 shows that the different species capture per permanent plot did have little effect on the allocation of relevés to the SALT97-type. Only in PQ7 allocation to different main types (J-type vs. R-type) occurred. This is a species-rich PQ in which different species are codominant. The different allocation is caused by a difference in the number of species occurring high in the salt-marsh zone (so called R-species). However, an error occurred, as the species *Odontites vernus* was not recognised by SALT97. The algorithm uses the subspecies name *Odontites vernus ssp serotina*, which in fact is the same in these relevés. If this species name would have been used, all six relevés would have contained more R-species and been addressed as 'Rg-type'.

No other examples were found of the SALT97 typology being affected by incorrect species identification or missing of species. Therefore, it is concluded that the species capture uncertainties does result in negligible uncertainties in the vegetation typology.

**Seasonal aspects**
According to Kirby et al. (1986) and McCune et al. (1997) another important source of uncertainty in both species list and cover estimates are seasonal fluctuations. Kirby et al. (1986) found that for woodland studies the effect of changing the observer had slightly less influence on the number of species than did altering the season of recording. As the year progressed so did the observers’ experience in visiting sites. Londo (1974) proposed to sample PQs during the spring and summer and to combine the species lists.

**Table 4.4.** Species cover (in %) for four relevés of salt-marsh vegetation on Schiermonnikoog during two dates in 1999. Over the course of the season the cover of annual species (*Salicornia europaea, Suaeda maritima*) and dominant species (*Elymus athericus, Artemisia maritima*) increased (* = unchanged).

<table>
<thead>
<tr>
<th>Relevé number</th>
<th>Date</th>
<th>25</th>
<th>64</th>
<th>67</th>
<th>39</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18-06</td>
<td>31-07</td>
<td>16-06</td>
<td>30-07</td>
<td>16-06</td>
</tr>
<tr>
<td>Suaeda maritima</td>
<td>10</td>
<td>40</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Salicornia europaea</td>
<td>10</td>
<td>30</td>
<td>20</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Limonium vulgare</td>
<td>&lt;5</td>
<td>*</td>
<td>10</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>Atriplex portulacoides</td>
<td>&lt;5</td>
<td>*</td>
<td>10</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Spergularia maritima</td>
<td>&lt;5</td>
<td>*</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Juncus gerardi</td>
<td>20</td>
<td>&lt;5</td>
<td>10</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Puccinellia maritima</td>
<td>&lt;5</td>
<td>*</td>
<td>30</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Spartina townsendii</td>
<td>&lt;5</td>
<td>*</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Triglochin maritima</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plantago maritima</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Festuca rubra</td>
<td>70</td>
<td>*</td>
<td>70</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Elymus athericus</td>
<td>30</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artemisia maritima</td>
<td>20</td>
<td>50</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Anserina maritima</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agrostis stolonifera</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trifolium repens</td>
<td>&lt;5</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 4.4 shows some examples of changes in species cover in salt-marsh relevés of Schiermonnikoog between May and August 1999. As salt-marsh vegetation cover increases during spring and summer, it is generally recommended to sample salt-marsh vegetation in The Netherlands for the period July-September.

Plot size and shape
Differences in plot size affect the species list and the cover estimation of plant species and with that the description of vegetation types. In vegetation science the plot size is normally independent of sample size. According to the tradition of the Braun-Blanquet method a relevé is chosen in such a way that it is representative for a vegetation type (Braun-Blanquet 1964). A plot of a given size is supposed to be representative if its floristic composition is similar to that of other plots (of the same size) taken from the same stand (Barkman 1989). This is a circle-reasoning, and therefore, can only be validated afterwards. Westhoff et al. (1995) give three criteria for the plot size: homogeneity, minimal area and, for efficiency reasons, maximal area. The minimal area is defined as the plot size beyond which the species-richness fails to increase, or increases only slightly (Kenkel & Podani 1991). The minimal area is often determined through interpretation of a species-area curve or by similarity analysis (Westhoff et al. 1995; Barkman 1989). In practice a plot size is chosen dependent on the scale and heterogeneity of the vegetation patterns, in a way that there is an optimum relation between the completeness of the species list and the constraints for relevé recording. Often this is a plot size with an area little larger than the minimal area (Westhoff et al. 1995). Kenkel & Podani (1991) state that traditionally the minimal area approach is applied for the determination of the plot size necessary for a representative sample of the vegetation. Van der Maarel (1996) argued that application of the minimum area may underestimate species capture, due to small-scale species dynamics. He proposed to use a maximum area instead. In practice, the plot size depends on the scale and heterogeneity of the vegetation patterns and is determined by expert knowledge. Westhoff et al. (1995) mention the following ‘guidelines’ for plot size:

- 0.1-0.3 m² for vegetation stands of bryophytes and lichens,
- 1-4 m² for grazed grasslands,
- 5-10 m² for hayed grasslands,
- 20-40 m² for shrub vegetation,
- 100-200 m² for woodlands.

In the field test no effect of plot size on the species capture or vegetation typology was found (figure 4.1). It is concluded that the relevés were made according to the homogeneity principle, in which case plot size uncertainties are negligible. Bormann (1953) studied the effects of plot shape in field sampling. He showed that rectangular plots result in statistically more precise estimates than circular plots. In this thesis, only rectangular plots are used.

Species abundance assessment
The uncertainty in the abundance assessments contains two aspects: resolution (abundance scale) and accuracy.
At the RWS-MD the relative abundance of plant species in a plot is estimated with a logarithmic scale, based on the scale of Barkman, Doing & Segal (1964) (table A.5 in appendix 3). This abundance scale is based on the combined estimation of Braun-Blanquet
This scale has a long history and tradition in vegetation science (Westhoff et al. 1995) and there is no need to discuss the classes of the application described in this thesis. For other applications different recording scales may be considered. For the estimation of species abundance in permanent plots a decimal scale is commonly used, as this scale enables quantitative analyses (Londo 1976). The abundance scales below 5% are sometimes interpreted differently by various observers. The influence of this interpretation on the description of vegetation types is considered negligible.

The field test showed that the relation between the mean cover assessment and the standard deviation is a kind of optimum curve (figure 4.2). The error is relatively low at low and high cover values and relatively high at in-between cover values. The error is also higher for ‘difficult’ cover assessments, probably because more visual confusion occurs. Furthermore, the effect of different structure layers on the assessment accuracy has not yet been studied.

The inaccuracy of the cover value for species occurring in low abundance is increased by differences in plot location (figure 4.3) as especially at an abundance of 0 to 30% the standard deviation is larger. For species with a cover of more than about 50% plot location (within the same photo-element) had no effect on the cover assessment. The standard deviation may increase among relevés made in the same photo-element in different land units, but this has yet to be tested.

For calculations with cover values pragmatic uncertainty intervals have been defined in table 4.5 for ‘easy’ and ‘difficult’ cover assessments. These intervals are based on the cover assessment intervals from the test. The intervals equal about the mean of the interval class plus/minus 2 times the standard deviation. Therefore, the uncertainty intervals may be considered as 95%-reliability intervals.

Table A.7 in appendix 4 shows that the different cover assessments per permanent plot did have no effect on the allocation of relevés to the SALT97-type. It is concluded that cover assessment uncertainty has negligible effects on vegetation typology. These results are in accordance with Lepš & Hadincová (1992), who concluded that ‘the visual estimate of species cover should not be a major problem when obtaining information of relevés’.

The influence of plot size and location, species capture and cover assessment on the typology will increase when:

<table>
<thead>
<tr>
<th>Table 4.5. Pragmatic uncertainty intervals for cover assessment of plant species in a relevé</th>
</tr>
</thead>
<tbody>
<tr>
<td>abundance code</td>
</tr>
<tr>
<td>parameters that are visually confused</td>
</tr>
<tr>
<td>0-5%</td>
</tr>
<tr>
<td>0-10%</td>
</tr>
<tr>
<td>0-20%</td>
</tr>
</tbody>
</table>
• the typology is more detailed;
• the typology is based more on species occurring in low abundance and with low presence;
• the typology is based more on codominant species;
• the cover value is close to the criterion for distinction between two classes;
• a vegetation stand is sampled that represents a transition between distinguished vegetation types.

In cases where these aspects affect the typology, expert-knowledge is needed for correction (see §4.3).

4.3. Vegetation classification test

4.3.1. Method

In a test 62 relevés made on the salt marsh of Schiermonnikoog in 1999 have been classified by the SALT97-algorithm. This preliminary classification has been clustered independently by eight surveyors, resulting in eight classification tables.

4.3.2. Results

In table A.9 (appendix 4) the distinguished relevé clusters are shown, together with the classification according to SALT97. Vertical black lines show the boundaries of classes distinguished by the different persons. To analyse the causes for differences, the relevés have been divided into two categories. The first are those relevés that have been classified in the same way, in general (light grey SALT97-code). The second are those relevés that have been classified differently, in general (dark grey SALT97-code). The latter make up 23% of the relevés classified by SALT97.

There are several causes why relevés have been classified in different ways:

• Some relevés are transition stages between clear vegetation types. These relevés have been classified by different persons as either type A, type B or a new (transition) type. Examples of this situation are relevés 128, 69, 23, 46 197, 162 and 133.
• Some persons show a trend to lump and others to split vegetation types, resulting in different detail levels. Examples are relevés 205 196, 28, 26, 161 and 192. Due to this difference the number of distinguished vegetation types in the data set varied from 11 to 22.
• Some relevés have been distinguished by SALT97 as a separate type, based on the abundance of one or more species, although these relevés do not differ much in total floristic composition from other relevés. Examples are relevés 18 (split because of the cover of *Limonium vulgare*) and relevé 174 (split because of the abundance of a.o. *Sagina maritima* and *Plantago coronopus*). Some surveyors maintain these relevés as a separate type, others lump them together.

In general, individual relevés are classified differently because they represent transition situations (‘transition relevés’) or because they differ in their floristic composition from all others relevés (‘dustbin relevés’). Relevés that are classified consistently are apparently good representations of a vegetation type. These are termed ‘core relevés’. Transition relevés are
clustered as one of the two vegetation types between which they form a transition or as a new ‘transition type’. Dustbin relevés are either lumped with the most similar cluster or maintained as different vegetation types. The choice of either ‘generalisation’ or ‘splitting’ of vegetation types is consequential to the number of vegetation types counted in the test.

4.3.3. Discussion

There has been much discussion on the classification subjectivity in the Braun-Blanquet method (a.o. Barkman 1990; Mucina 1997). Computer based algorithms have been developed in order to make classification more independent from personal expert knowledge. Many studies have shown that different algorithms produce different results in vegetation classification or ordination and some techniques are sensitive to changes in the data or in the input order of species and relevés (Jensen 1970; Minchin 1987; Tausch et al. 1995; van Tongeren 1996; Podani, 1997; Oksanen & Minchin 1997). Up to now there are no algorithms that produce completely satisfying results.

A comparison of SALT97 and ASSOCIA (a programme developed by Van Tongeren, which uses a maximum likelihood algorithm to calculate the relation of individual relevés and clusters of relevés to the Dutch reference system of plant communities) for the classification of vegetation relevés of the *Puccinellion maritimae* resulted in about 80% (on average) correct classified relevés for both SALT97 and ASSOCIA (Janssen & Kers in prep.).

The use of a standard typology, like SALT97, implies that vegetation stands which represent transitions of vegetation types are not distinguished. In those cases the standard typology does not match the field situation, and should not be used strictly, in order to distinguish ecologically meaningful vegetation types. Treitz et al. (1992) showed that a subjective vegetation classification by an expert provided much better relationships with spectral classes from a digital RS-image and therefore a higher map accuracy, than objective vegetation classification by the algorithm TWINSPAN. In general, an expert assessment is always needed for construction of the final classification.

However, due to the subjective influence of persons, there is much difference between classifications by different people. To reduce the subjective influence the following general ‘rules of thumb’ are recommended:

- to distinct between core, transition and dustbin relevés;
- to bring hierarchy in the vegetation classification;
- to decide for transition relevés whether they are clustered with one of the types between which they form a transition or as a separate type; an ordination diagram may aid in this decision; for monitoring it is recommended to record the decisions on ‘transition’ and ‘dustbin relevés’, in order to repeat them in a sequential vegetation classification;
- to discuss the decisions and the final result of a classification with different experts.

Besides, general quality criteria for a vegetation typology are:

- a vegetation type should have differential species or species-groups compared to other types;
- all vegetation types should be ecologically unique and relate to different process stages that are relevant for the mapping aim;
- the vegetation types should be ordered in a logical sequence (in relation to the research aim);
• the species should be grouped in ecologically meaningful groups (see Schaminée et al. 1995b).

By considering these recommendations, a local reference typology may be constructed for any specific area and mapping aim, in which the field variation is shown in an optimal way that is consistent over time. New vegetation types may be added or split off. Owing to the field variation and seasonal variation vegetation types of different years will hardly ever be completely identical, however, on one hierarchical level, the types are the same in different years. On a certain hierarchical level, this local reference typology must match more regional typologies like the SALT97 and the salt-marsh communities described by Schaminée et al. (1998), in order to use the ecological information that is available via these reference types. There is likely to always be a discussion on the consideration whether some variation is caused by seasonal fluctuation or by (long-term) change of the type (into a new type). To analyse seasonal fluctuations and gradual changes for a vegetation type over a longer period, it is necessary to sample the vegetation every mapping year. A combination of stratified field sampling and observations of PØs may be used to distinguish between changes of different forms of vegetation dynamics. How complementary both methods are is discussed in §9.4.

In chapter 8 of this thesis, vegetation types of different years have been combined into one reference typology. Some adaptations in the original typologies were made, to make them more consistently.

The local vegetation types of Ameland have been allocated to reference types by expert-knowledge. In a different way, the similarity between local types of each survey year and reference types may be calculated by indices. Sanders & van Wirdum (1994) calculated similarity-measures to determine the similarity between vegetation types of two years from dune slacks on Ameland. This worked well in general, though they encountered some problems with differences in structure layer and differential species that occurred in low abundance. If vegetation types of sequential maps have a low similarity, it is possible to translate the vegetation types into an ecological indication value, for example an Ellenberg value (Ellenberg et al. 1991). Differences in the spectrum or the mean of Ellenberg values may be used to analyse shifts in process stages. In this way the parameters in the sequential maps are similar and the maps may be compared for this parameter. This procedure is a way of generalisation and reduces the information in the map. An example is given by von Asmuth & Tolman (1996).

When using a local reference typology, there is a dilemma when applying the Landscape Guided Method. Because vegetation types should be related to photo-characteristics, the relation between vegetation types and photo-elements should be 1:1. For transition relevés this may cause a problem, as they, for example, should be clustered with type A, but have the photo-characteristics of type B. To make photo-interpretation possible, they have to be clustered with type B. This causes inconsistency of the vegetation typology in time (Janssen & Kers in prep.).

There are two solutions for this dilemma:
• It is possible to classify transition relevés inconsistently, as this is needed for photo-interpretation. If the transitions concern small, irrelevant areas, the uncertainties may be considered negligible. Alternatively, the inconsistencies have to be registered and considered in a vegetation change analysis.
• A way to prevent the inconsistent clustering of transition relevés, is the application of a photo guided field survey for the photo-elements of concern.
4.4. Conclusions

Field sampling
It is concluded that for vegetation mapping by remote sensing a stratified random sampling scheme, based on spectral classes, is the most appropriate, as it makes sure that small, but important areas are represented in the sample and it provided stable results in the tests. For reasons of efficiency and reliability, the sample should consist of a cluster of an average of 10 and a maximum of 25 pixels on a digital image (after Congalton 1988b) and at least five sample clusters per class (after Hay 1979). Field samples for photo-interpretation are considered as sample clusters of sufficient size, so at least five samples per class are needed. More heterogeneous classes (thematically or spectrally) need a larger sample size.

Uncertainties in field sampling (in species capture, plot size, plot location and cover assessment) had negligible effects on the classification of relevés according to the SALT97 typology. It is concluded that the expertise of the observers was of a quality that guaranteed no effect of field sampling uncertainties on vegetation typology.

The effect of the different uncertainties on the typology may increase as the typology becomes more detailed or more based upon species occurring in low abundance or with a low presence or more based upon codominant species. Furthermore, classification uncertainty increases as more stands are sampled that represent a transition between various types. In these cases, expert knowledge is needed to correct for effects of sampling uncertainties on the vegetation typology.

In a monitoring programme field work should be carried out in the same season every year to prevent sample uncertainties due to seasonal differences.

Vegetation classification
In the test on average 77% of the classification by the SALT97-algorithm was accepted by the surveyors. In general the same relevés were accepted by different surveyors (the ‘core relevés’). The main sources of differences in vegetation classification were gradual transitions (‘transition relevés’) and relatively large deviation of a single relevé from all other relevés (‘dustbin relevés’). This resulted in subjective decisions on cluster number and boundaries.

For monitoring purposes, the expert-influence on vegetation typology should be reduced as much as possible. However, as classification algorithms do not produce completely satisfying results, the subjective expert-influence can never be reduced totally.

For example, SALT97, which is aimed to represent salt-marsh types of the whole Netherlands, did not provide a 100% good classification for the local variation in the set of relevés. Therefore, in a monitoring project, it is recommended to construct a local reference typology for any certain area and mapping aim. The local reference typology of the first year should get much attention in order to be ‘optimal’ (in relation to the mapping aim). The typologies of sequential surveys should be matched to the first at a certain hierarchical level and the typology must match more regional typologies like the SALT97 and the communities described by Schaminé et al. (1995-1998) and Stortelder et al. (1999).

A dilemma is that the use of any standard typology may conflict with the Landscape Guided Method as a 1:1 relationship between photo-elements and vegetation types is needed to translate photo-elements to vegetation types. If these adaptations are not negligible, a photo guided field survey is needed for the photo-elements of concern, to prevent translation uncertainty (see §6.1).