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Oskarshamn site investigation

Validation of marine benthic vegetation models

Random sampling in shallow marine areas

Erik Wijnbladh, Svensk Kärnbränslehantering AB

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October 2007

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Abstract

This study is aimed at validating the two previously constructed models on macrophyte vegetation in the Oskarshamn site investigation area. The study was made by comparisons between model output and studies of vegetation cover in situ. Vegetation was inspected by visual estimates of vegetation cover at previously determined sites. The vegetation estimates were performed by scuba divers. The results show that one of the models (made by stratified interpolation between samples) has higher predictive power than the other (based on correlations between vegetation and physical parameters) especially to predict occurrence/absence of certain vegetation communities. Both models make less accurate predictions of vegetation cover at individual sites at the investigated scale (20 · 20 m). However, the models do perform better when estimating average biomass at larger, basin-scale. This issue is of large interest since ongoing safety assessment is mainly working with models with a resolution at the scale of individual basins.

Sammanfattning

Denna studie har utförts för att validera de två vegetationskartor som utförts på makrofyter i Oskarshamns platsundersökningsområde. Studien har utförts genom att besöka slumpvis utvalda lokaler och inventera vegetationstyp och täckningsgrad på dessa lokaler. Data har sedan jämförts med förutsagda resultat från de två modellerade vegetationskartorna. Den ena av modellerna (i huvudsak gjord genom stratifierad interpolering mellan punkter) ger mer träffsäkra prediktioner än den andra (modellerad utifrån korrelation mellan vegetation och fysiska variabler) särskilt i fråga att förutsäga förekomst/frånvaro av en viss vegetationstyp. Båda modellerna har låg prediktionsförmåga när det gäller täckningsgrad av vegetationen på individuella lokaler (20 · 20 m). På en större, bassäng-skala har båda modellerna dock bättre möjlighet att förutsäga medelvärden för biomassa. Denna fråga är dock av stort intresse då pågående säkerhetsanalys i huvudsak arbetar med en modellerad upplösning på en nivå av enskilda bassänger.

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1 Introduction

This document reports the results gained by the Validation of marine vegetation maps, which is one of the activities performed within the site investigation at Oskarshamn. This activity is part of the annual "Fieldweek" performed by SurfaceNet, a work group modelling surface ecosystems.

Previously, two separate models of benthic vegetation has been performed by SKB /Fredriksson and Tobiasson 2003, Carlén et al. 2007/ in order to quantify biomass and distribution of benthic macrophytes in the Laxemar area. Both studies are based on a large number (> 1,200) of individual samples gathered from investigations that are part of the Oskarshamn site investigation programme. The two models differ in algorithms and their basic assumptions. The study by /Fredriksson and Tobiasson 2003/ is primarily an interpolation of macrophyte cover between sample locations. This model is expected to have a high predictive power in estimating vegetation cover in the area, but lacks the ability to predict any macrophyte cover at sites outside the modelled area. The model by /Carlén et al. 2007/ has algorithms based on a number of physical parameters with large spatial cover and thus is more suitable to model macrophyte cover in non surveyed areas. However, the predictive performance of the two models within the Oskarshamn site area has not been properly validated. This is necessary in order to guide future modellers at SurfaceNet to use the most appropriate model to generate data for future analysis and modelling. It is also important to supply SurfaceNet with an estimate of uncertainties associated with output data from the two models.

The purpose of the present study was to validate the predictive performance of the two models within the Oskarshamn site area. This was done by observations of vegetation type and coverage at 23 previously randomly selected stations in the inner basins within the Oskarshamn site investigation area, see Figure 1-1. The study was performed during the "SurfaceNetFieldweek" in august 2007.

The results from this study are presented in Appendix 1 and are stored in the database SICADA and GIS database SDE and are traceable via this report number.

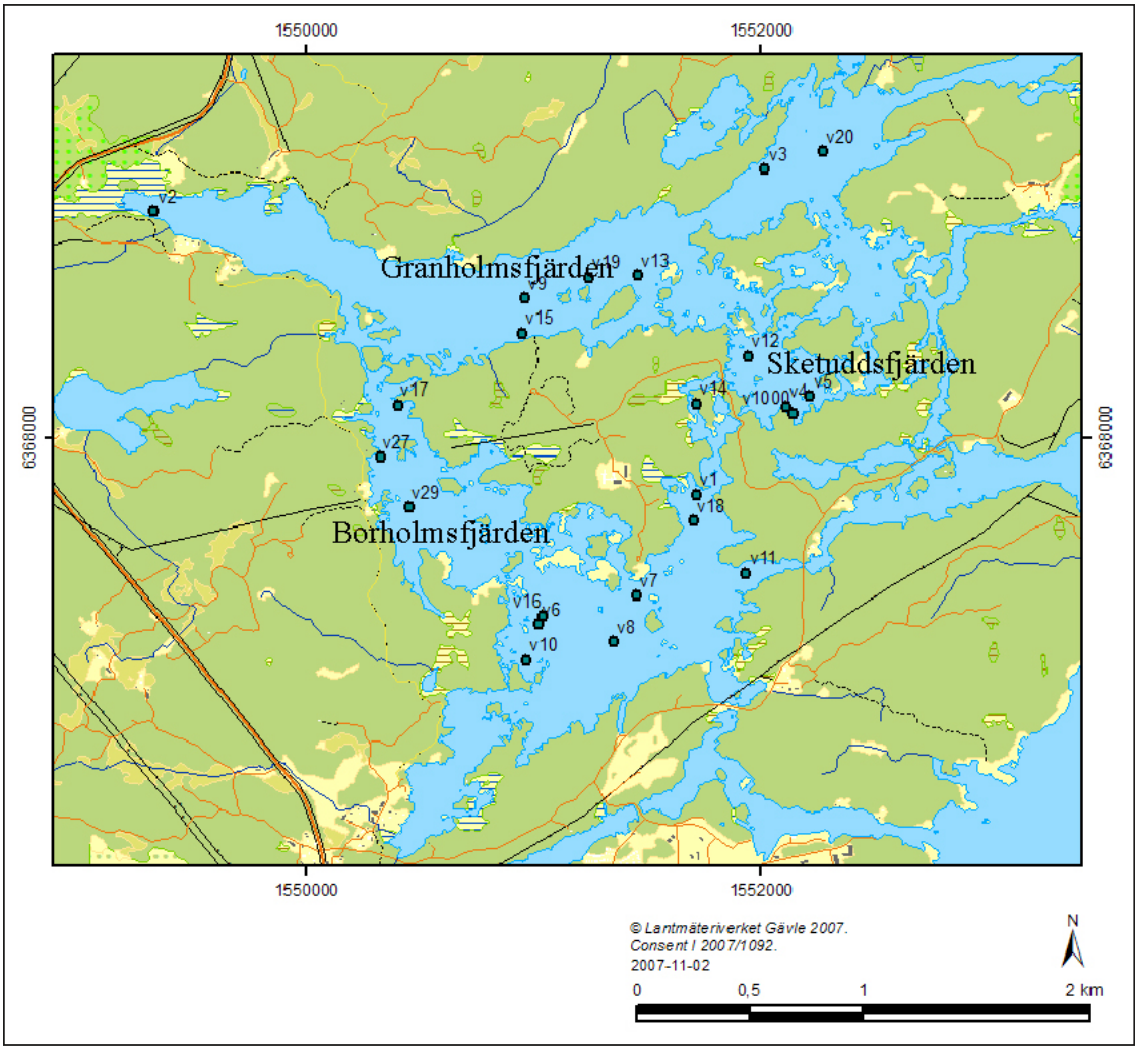

Figure 1-1. *The inner bays in the Laxemar area and circles showing the sample sites in this study.*

2 Objective and scope

The aim of this study was to validate the predictions made in the published studies of vegetation models. Part of the validation was to investigate if any one of the models over- or under estimates the amount of macrophytes in the area. The outcome of this validation is to facilitate the choice of model to use for further modelling of mass flux in the ecosystem. This report is also providing an estimate of uncertainty associated with the output data from the two models. Attaching estimates of uncertainty is of crucial importance when using output data in further risk/security modelling.

3 Execution

3.1 General

The validation was made by inventory of previously determined stations within the Oskarshamn site area. Coordinates for 50 stations were generated with the “Random” function in MS Excel and the stations were numbered and plotted on a map. From these numbers, stations were chosen in ascending order. In total 23 stations were visited during two days; 22–23 August 2007. The selected stations were visited by boat, using a GPS, and investigated as follows.
At each station a scuba diver recorded percentage coverage of all vegetation. This data was later compared with the predicted vegetative cover of the two models.

3.2 Preparations

In order to make a validation of the models, it is important that the output data from the model is compared with an accurate observation of actual vegetation. Since the vegetation was estimated by visual inspection, each individual diver was considered a possible source of bias. In order to estimate the effect of individual diver on the recorded observations, both divers made recordings at the same station. It turned out that the two divers had very similar recordings, even at stations with diverse vegetation. The role of each diver was therefore considered negligible.

3.3 Execution of field work

The boat was anchored and a scuba diver descended. A 2 m line was attached to the anchor line at one end and the diver at the other end. The diver then swam one revolution and observed the vegetation within a 2 m corridor, 1 m at each side of the stretched line. A marker was dropped at the starting/finishing point. The investigated area had the geometrical shape of a doughnut with an inner diameter of 4 m and an outer diameter of 6 m. The investigated area was 25 m^2, considered to be a reasonable area to estimate the general vegetative cover at each station, while still being practically feasible. The diver recorded percentage coverage of all macroscopic plant species within the investigated area.

3.4 Analyses and interpretations

The predictability of each model was estimated by comparison with collected data of actual macrophyte coverage. The validity of each model was made in a hierarchical fashion. The validity was examined using all individual stations, i.e. the difference between modelled and observed data for each station. The validity of each model was also examined at the scale of bathymetrically distinct basins /cf Lindborg 2006, Section 4.3/. This was made by calculating the average vegetative coverage in each basin, using data from the stations therein. This average vegetative coverage was then compared to the dataset of observed vegetation, calculated in the same manner. All data on a basin scale were recalculated to gC/m^2 using relationships between cover and biomass described in /Fredriksson and Tobiasson 2003/. Biomass was transposed to annual means of gC/m^2, as described by /Carlén et al. 2007/, in order to make comparisons with the modelled data possible.

An often used measure of the difference between values predicted by a model and values actually observed in the modelled system is the root mean square error (RMSE). It is calculated in the following way:

$$RMSE = \pm\sqrt{\frac{\sum v_i^2}{n}}$$

where = individual deviation of each modelled value to observed value

and *n* = sample size

RMSE can be interpreted as a measure of goodness of fit of each model, relative to observed data. In order to facilitate the interpretation of RMSE, it has been normalised by dividing RMSE by the total range of values within the dataset:

$$NRMSE = \frac{RMSE}{v_{\max} - v_{\min}}$$

In order to investigate any bias in the models in the form of a systematic error, a paired Student´s t-test was performed between each model output and observed data. This way any consistent over- or underestimations of a model should be revealed. The test statistics *t* was calculated as follows:

$$t = \frac{\overline{d}}{\frac{s_d}{\sqrt{n}}}$$

where $\overline{d}$ the mean of the differences between modelled and observed vegetation in each station and $\frac{s_d}{\sqrt{n}}$ is the standard error of the differences, i.e. standard deviation divided by sample size.

3.5 Nonconformities

In order to maximise the number of recordings in different areas (basins), three stations were added to the previously selected visiting stations, namely station v27, v29 and v1000, see Figure 1-1.

4 Results

4.1 Observations and predictions of cover

4.1.1 Chara spp.

The modelled distribution of *Chara spp*. vegetation in the area is shown in Figure 4-1 and 4-2, below, together with the actual vegetation at the stations visited during this study. The model by /Fredriksson and Tobiasson 2003/ differs from observed values by approximately 18 percentage points, corresponding to a NRMSE value of 0.36. The estimated cover in the model by /Carlén et al. 2007/ differ by approximately 30 percentage points, resulting in a NRMSE value of 0.39. Percentage cover and summary statistics are presented in Table 4-1.

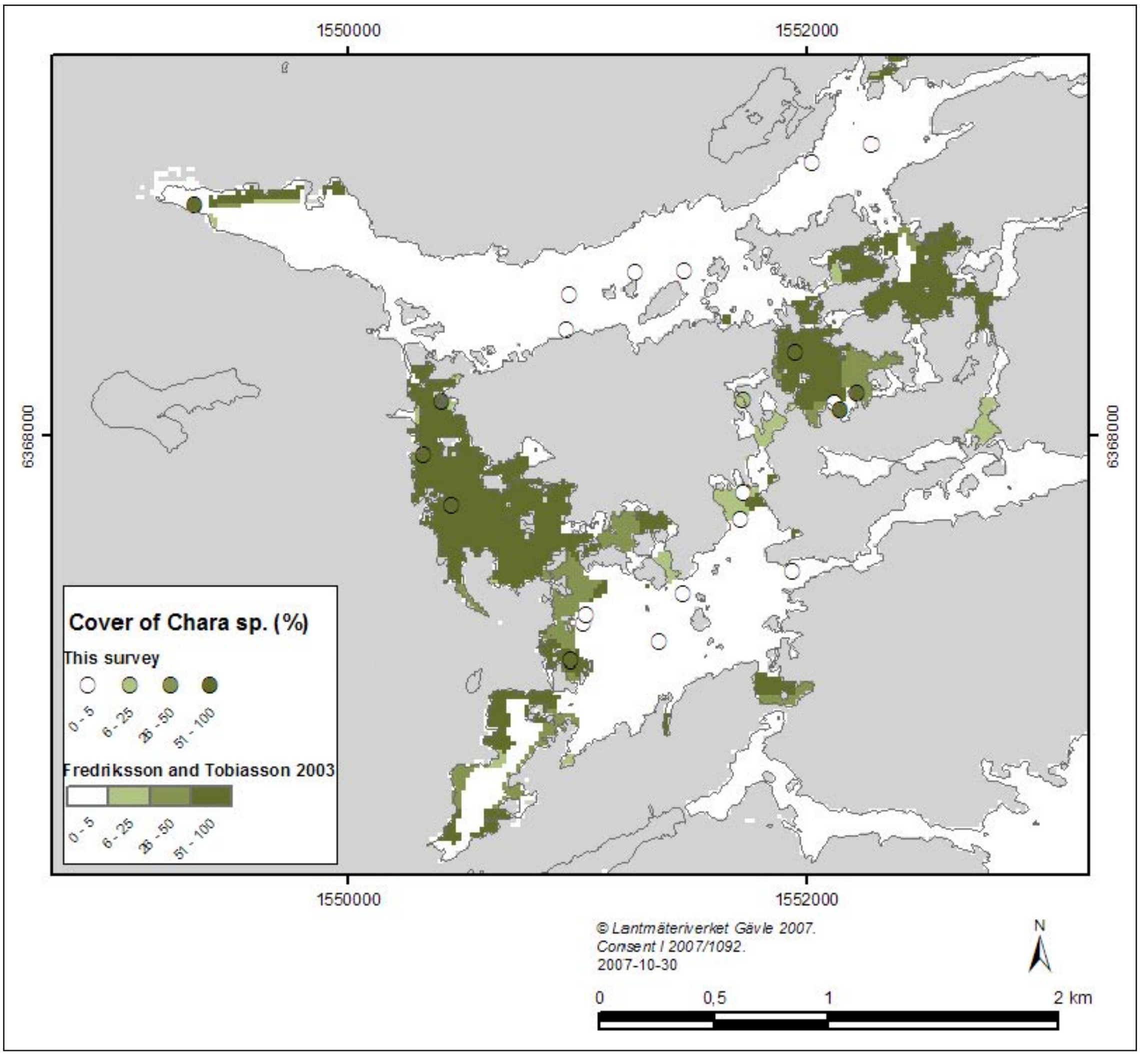

Figure 4-1. *Predicted distribution of Chara spp. as modelled by /Fredriksson and Tobiasson 2003/. The circles show Chara spp. vegetation at the stations investigated in this study.*

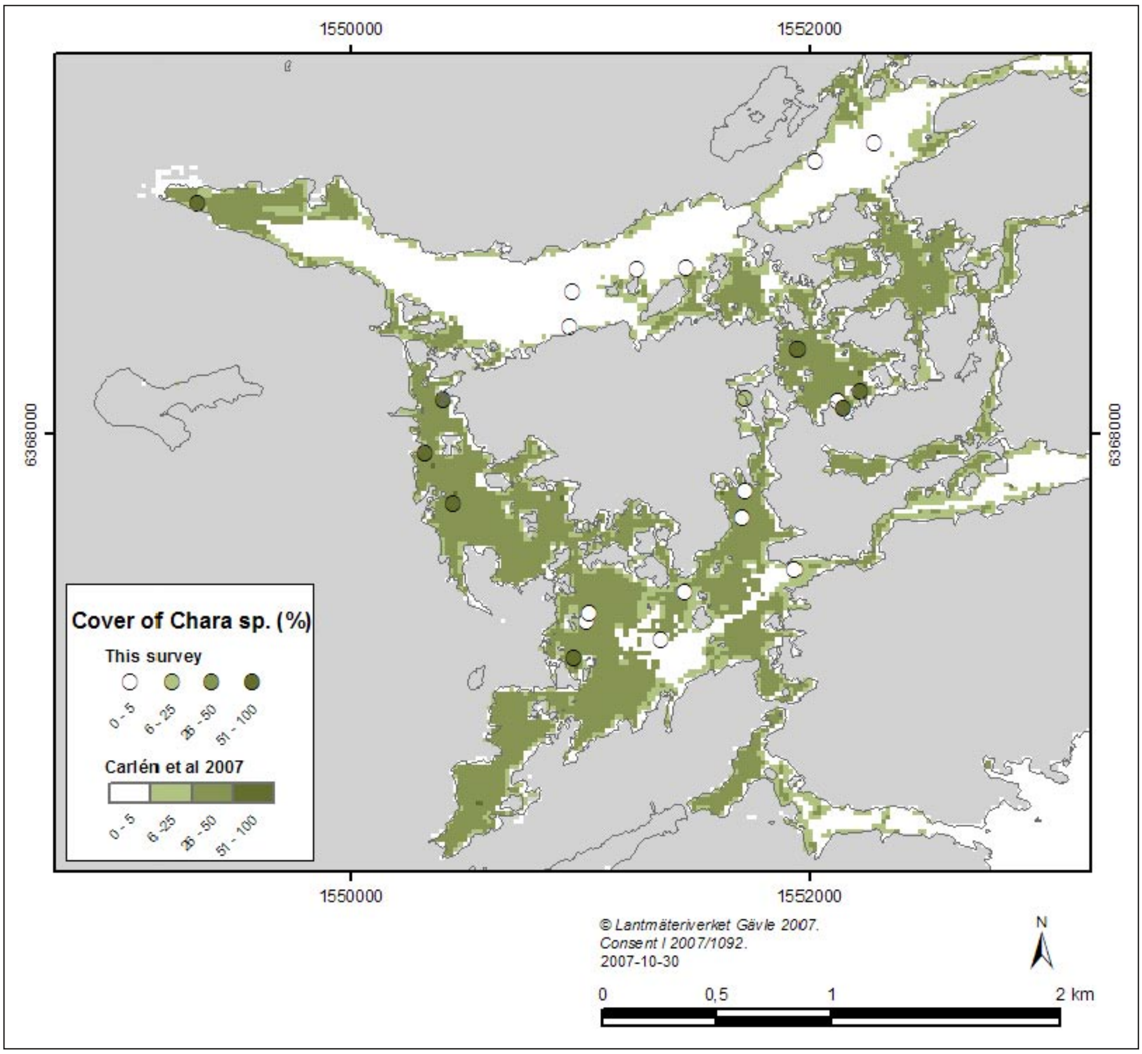

Figure 4-2. Predicted distribution of Chara spp. as modelled by /Carlén et al. 2007/. The circles show Chara spp. vegetation at the stations investigated in this study.

Table 4-1. Summary statistics for model data on *Chara spp*. vegetation.

	/Fredriksson and Tobiasson 2003/	/Carlén et al. 2007/	Observed
Percentage cover	25.6	23.5	32.6
RMSE	35.90	39.18	
NRMSE	0.36	0.39	
Paired t-test, p-value	0.36	0.30	
Correlation, r^2	0.41	0.27	

Figure 4-3 clearly illustrates the difficulty of using models to predict vegetative cover. The model by /Fredriksson and Tobiasson 2003/ has the highest accuracy and only fail to predict occurrence at three sites. It predicts an average cover of 26.5% (observed 32.5%). The model by /Carlén et al. 2007/ predicts a similar average cover (23.5%), but has a very low agreement with observed vegetation in the individual sites. Such a poor predictability was already seen when the model output was compared with original input data suggesting that the model was in need of calibration.

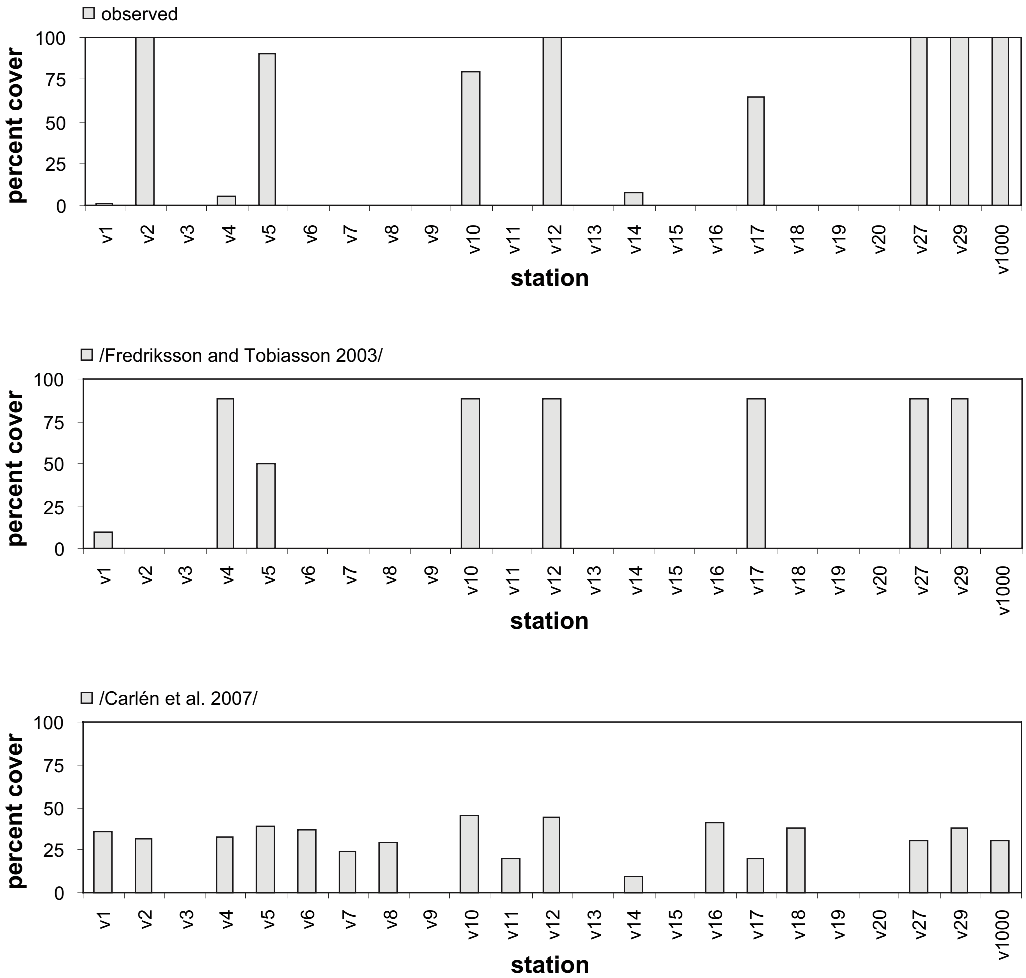

Figure 4-3. *a) Observed percent cover of Chara spp., compared to b) modelled cover by /Fredriksson and Tobiasson 2003/ and c) /Carlén et al. 2007/.*

Table 4-1 summarises the statistical data for the predictability of the two models. A general conclusion is that predictability is low with both models, although the model by /Fredriksson and Tobiasson 2003/ gives better results. The t-test suggest that none of the models systematically under- or overestimates *Chara spp*. vegetation cover. However, the correlation coefficient, r^2, suggests a rather poor fit between the Carlén model and observed values. This can be seen in Figure 4-3, where the model overestimates vegetation coverage where *Chara spp*. is sparse or absent and on the other hand it underestimates vegetation coverage at those stations where *Chara spp.* are dominating.

4.1.2 Vaucheria spp.

The modelled distribution of *Vaucheria spp*. vegetation in the area is shown in Figure 4-4 and 4-5, below, together with observed data, Similar to *Chara spp.* vegetation, as previously in Figure 4-1 and 4-2, the models differ from observed values at different degrees. The Fredriksson model differs from observed values only by 13 percentage points, corresponding to a NRMSE value of 0.34, slightly better than for *Chara spp*. The model by /Carlén et al. 2007/ differ by approximately 23 percentage points, resulting in a NRMSE value of 0.39. Percentage cover and summary statistics are presented in Table 4-2.

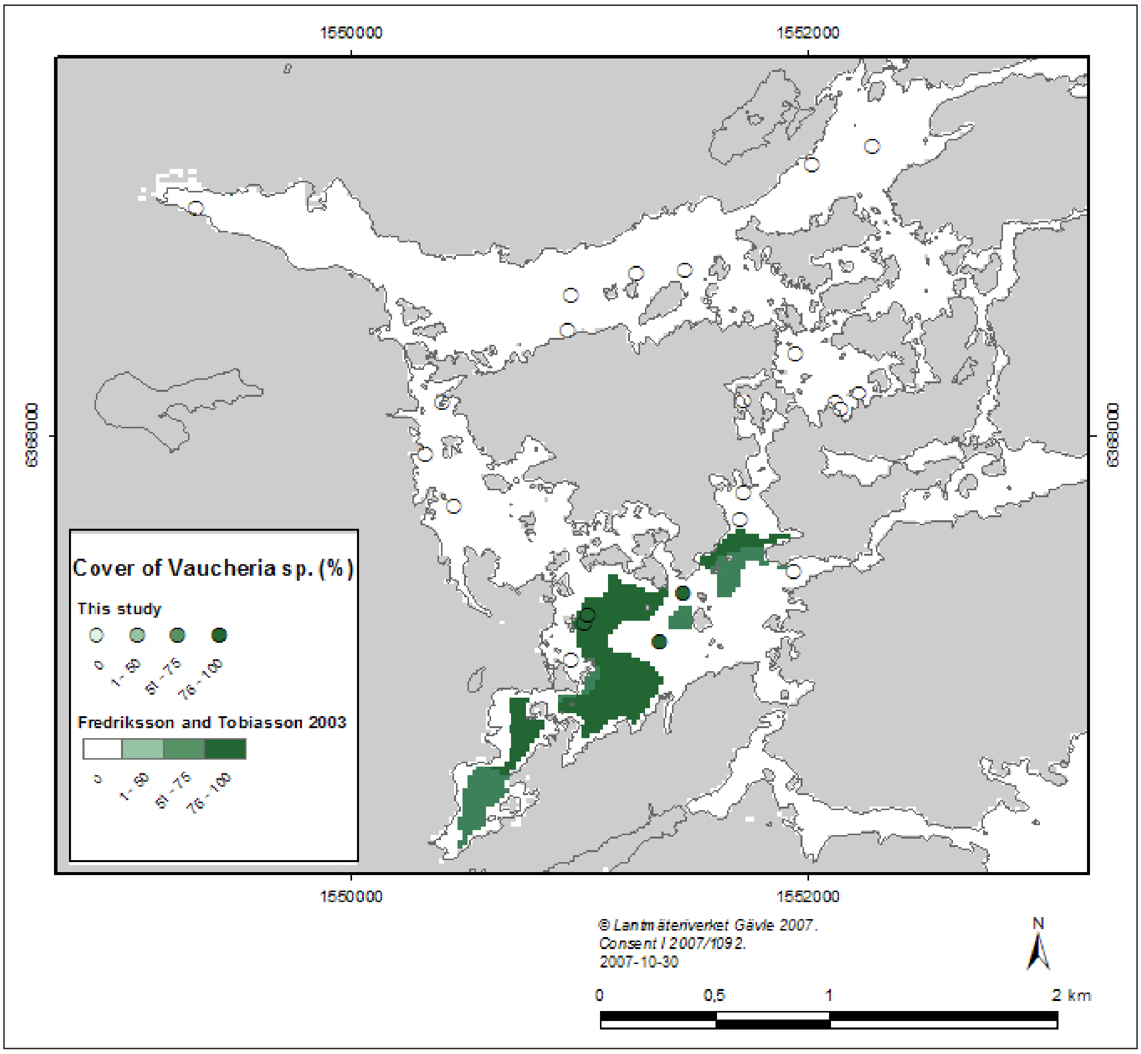

Figure 4-4. *Predicted distribution of Vaucheria spp. as modelled by /Fredriksson and Tobiasson 2003/. The circles show Vaucheria spp. vegetation at the stations investigated in this study.*

Table 4-2. Summary statistics for model data on *Vaucheria spp.* vegetation.

	/Fredriksson and Tobiasson 2003/	/Carlén et al. 2007/	Observed
Percentage cover	10.9	8.3	17.4
RMSE	33.57	39.06	
NRMSE	0.34	0.39	
Paired t-test, p-value	0.36	0.27	
Correlation, r^2	0.29	0.0019	

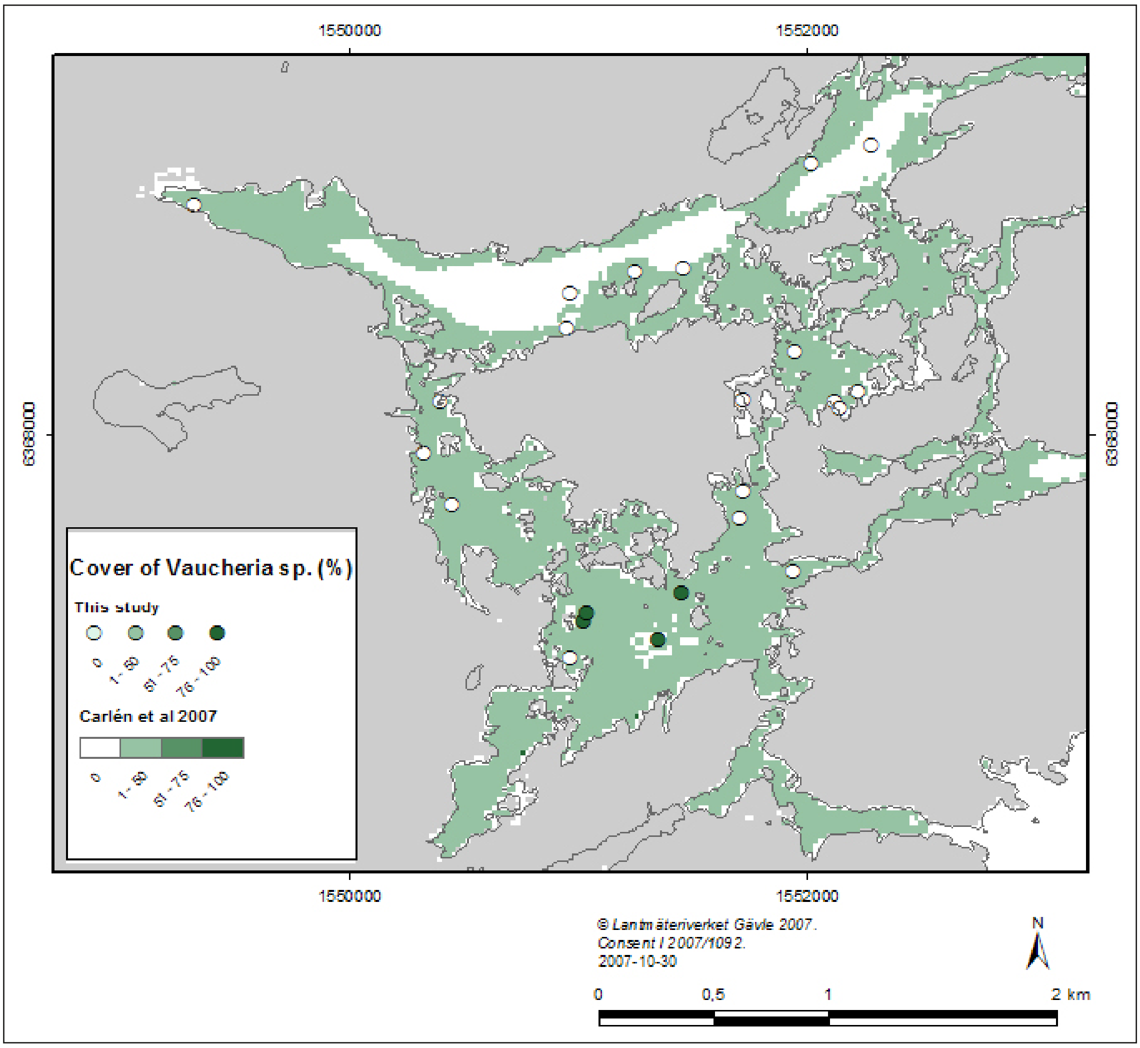

Figure 4-5. *Predicted distribution of Vaucheria spp. as modelled by /Carlén et al. 2007/. The circles show Vaucheria spp. vegetation at the stations investigated in this study.*

Figure 4-6 shows the predictability of the models at each station. Again, the model by /Fredriksson and Tobiasson 2003/ has higher highest accuracy and fails to predict occurrence at two sites and predicts occurrence in one site where *Vaucheria* was absent. Average cover was predicted to be 10.9% while observed was higher, 17.4%. /Carlén et al. 2007/ has a very low agreement with observed vegetation and average cover is less than half observed (8.3%). The reason for this is probably the same as mentioned in Section 4.1.1.

Table 4-2 summarises the statistical data for the predictability of the two models. General conclusions are that predictability is low with both models, although the model by /Fredriksson and Tobiasson 2003/ has better performance. T-test again suggests none of the models systematically under- or overestimates *Vaucheria spp*. vegetation cover. However, the correlation coefficient, r^2, suggests a more or less non-existing fit between the Carlén model and observed values. Again, this model overestimates vegetation coverage where *Vaucheria spp.* is sparse or absent and on the other hand it underestimates vegetation coverage at those stations where *Vaucheria spp.* are dominating. This trend is more obvious than for *Chara spp*., simply because there are fewer samples with *Vaucheria spp*. than with *Chara spp*.

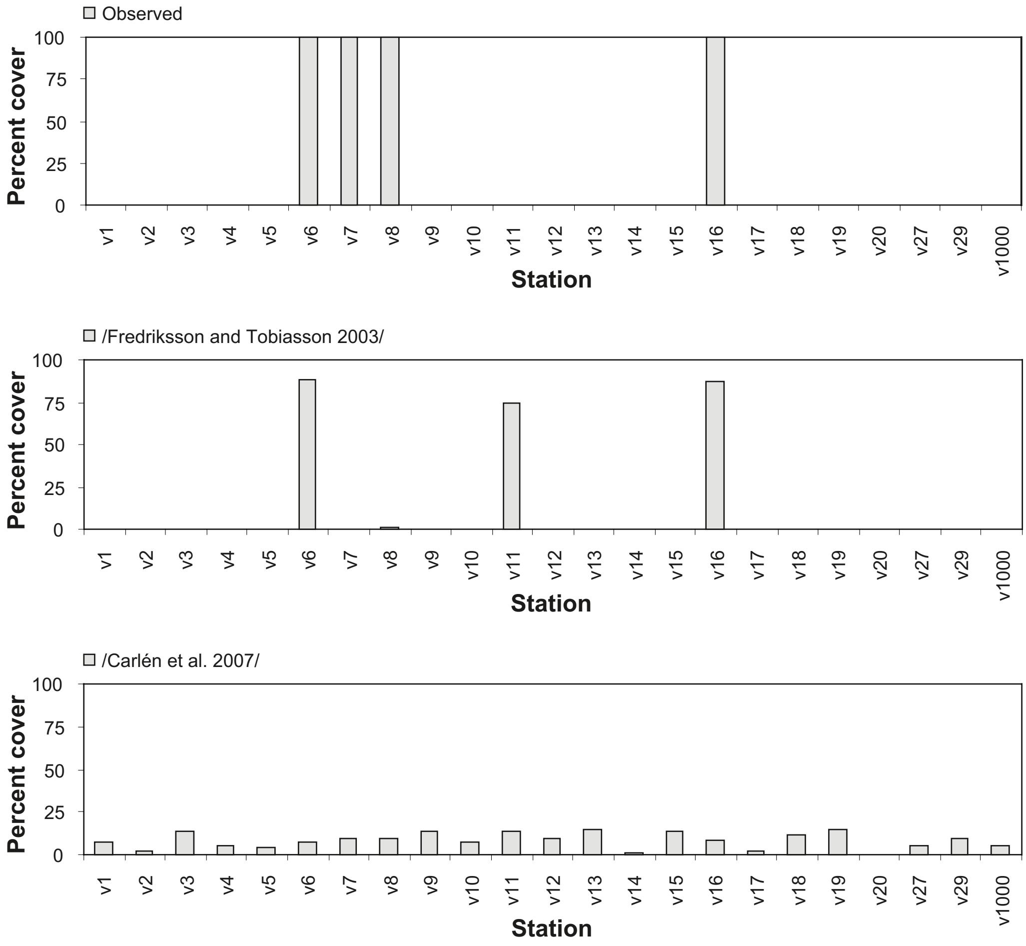

***Figure 4-6.** **a)** Observed percent cover of Vaucheria spp., compared to b) modelled cover by /Fredriksson and Tobiasson 2003/ and c) /Carlén et al. 2007/.*

4.1.3 Phanerogames

The model by /Fredriksson and Tobiasson 2003/ does not have any areas classed as dominated by phanerogames in the studied area. Therefore the only presentation on this vegetation class is Figure 4-7, where the vegetation cover modelled by /Carlén et al. 2007/ is compared with the observed cover during this study. Again, the model by /Carlén et al. 2007/ distributes vegetation in far more stations than observed. The model also underestimates the vegetation cover when you do find it, although this artefact is less pronounced in phanerogames than *Chara spp.* and *Vaucheria spp*.

4.2 Observation and predictions of biomass

When comparing total biomass abundance of vegetation, the models make slightly better estimates than for individual vegetation types; see Figure 4-8; 4-9; 4-10 and Table 4-3. When comparing Figure 4-10 with the summary statistics in Table 4-3, it may be surprising that summary statistics are not better for the Fredriksson and Tobiasson model. The main reason for this is that it makes fairly bad predictions at site v7 and v8. This is the reason for a p-value of 0.20 for the paired Students t-test, indicating the Fredriksson and Tobiasson model may have a tendency to slightly underestimate biomass (although this is not significantly proven). These sites had a full cover of *Vaucheria* vegetation. The model by /Carlén et al. 2007/ again predicts moderate vegetation at all sites, being similar to the observed average but missing the trends in the material.

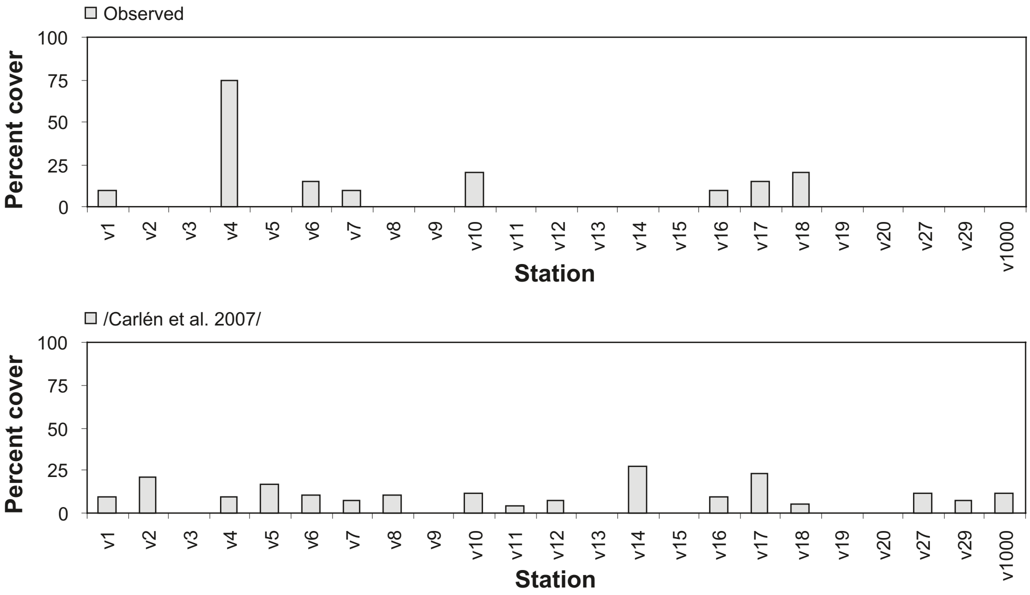

Figure 4-7. *a) Observed percent cover of Phanerogames compared to b) modelled cover /Carlén et al. 2007/.*

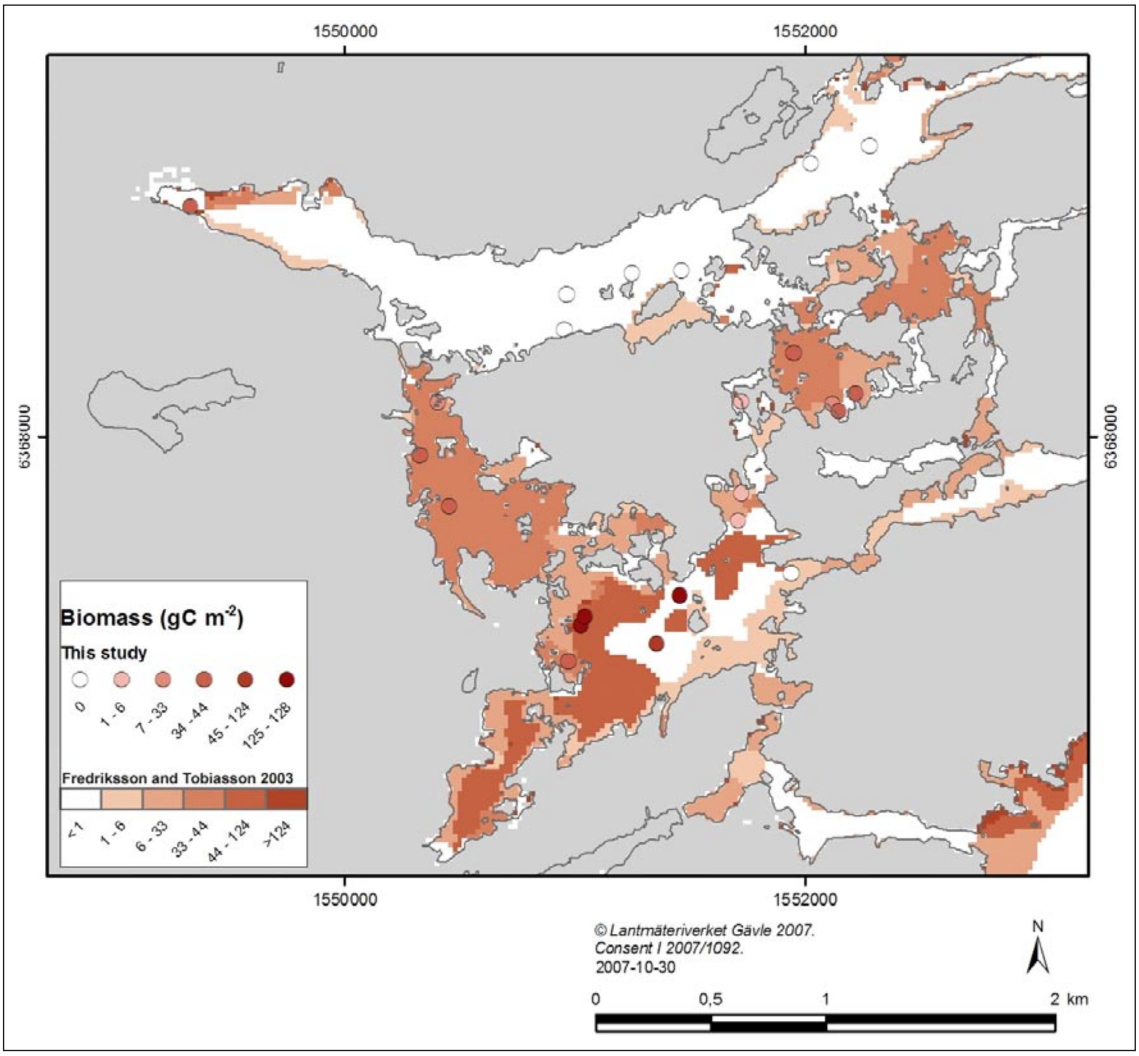

Figure 4-8. *Predicted distribution of total vegetation biomass (gC m^{-2}), as modelled by /Fredriksson and Tobiasson 2003/. The circles show vegetation at the stations investigated in this study.*

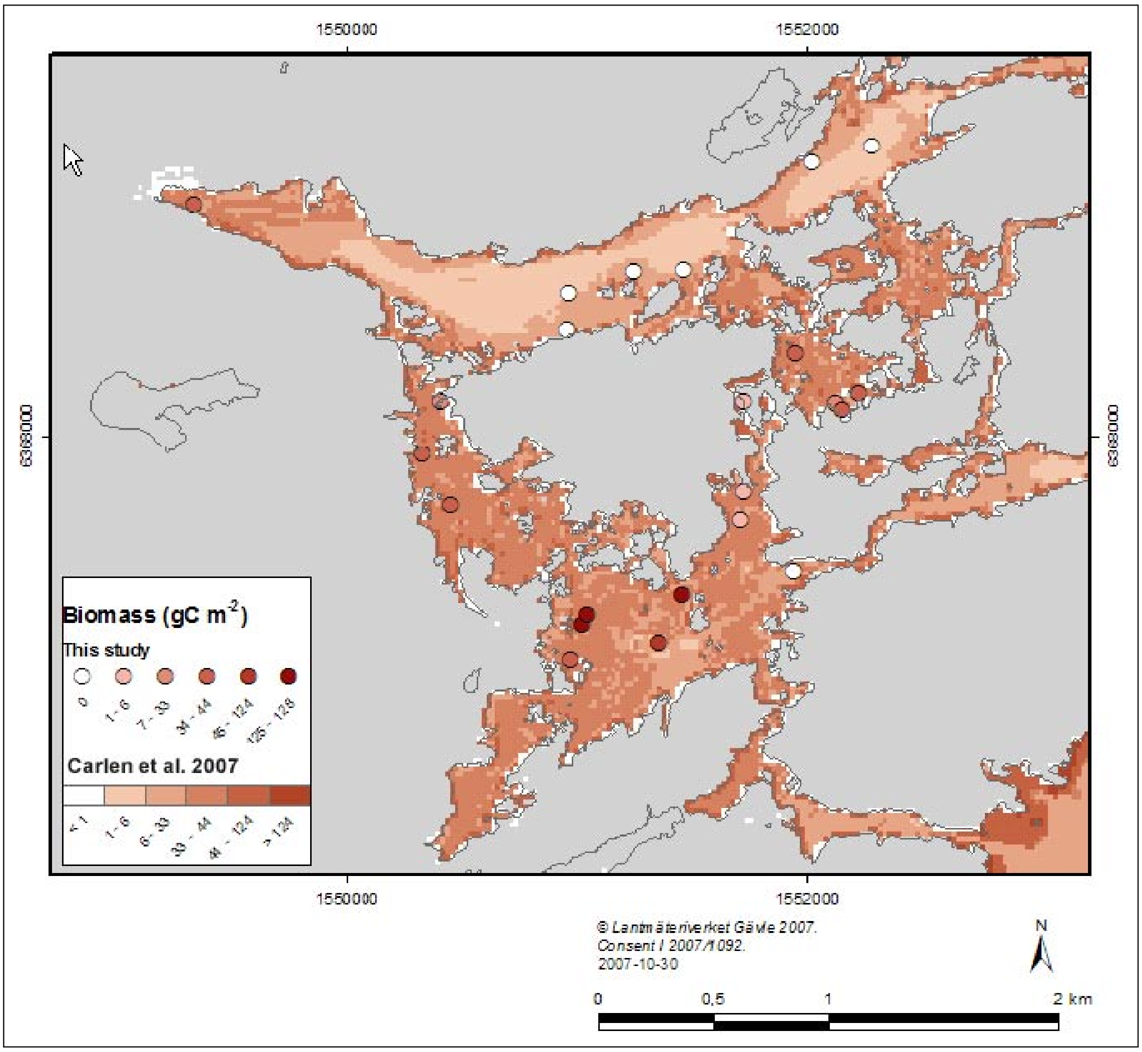

Figure 4-9. *Predicted distribution of total vegetation biomass (gC m^{-2}), as modelled by /Carlén et al. 2007/. The circles show vegetation at the stations investigated in this study.*

Table 4-3. Summary statistics for model data on total vegetation biomass.

	/Fredriksson and Tobiasson 2003/	/Carlén et al. 2007/
RMSE	43.4	43.2
NRMSE	0.34	0.34
Paired t-test, p-value	0.23	0.70
Correlation, r^2	0.21	0.06

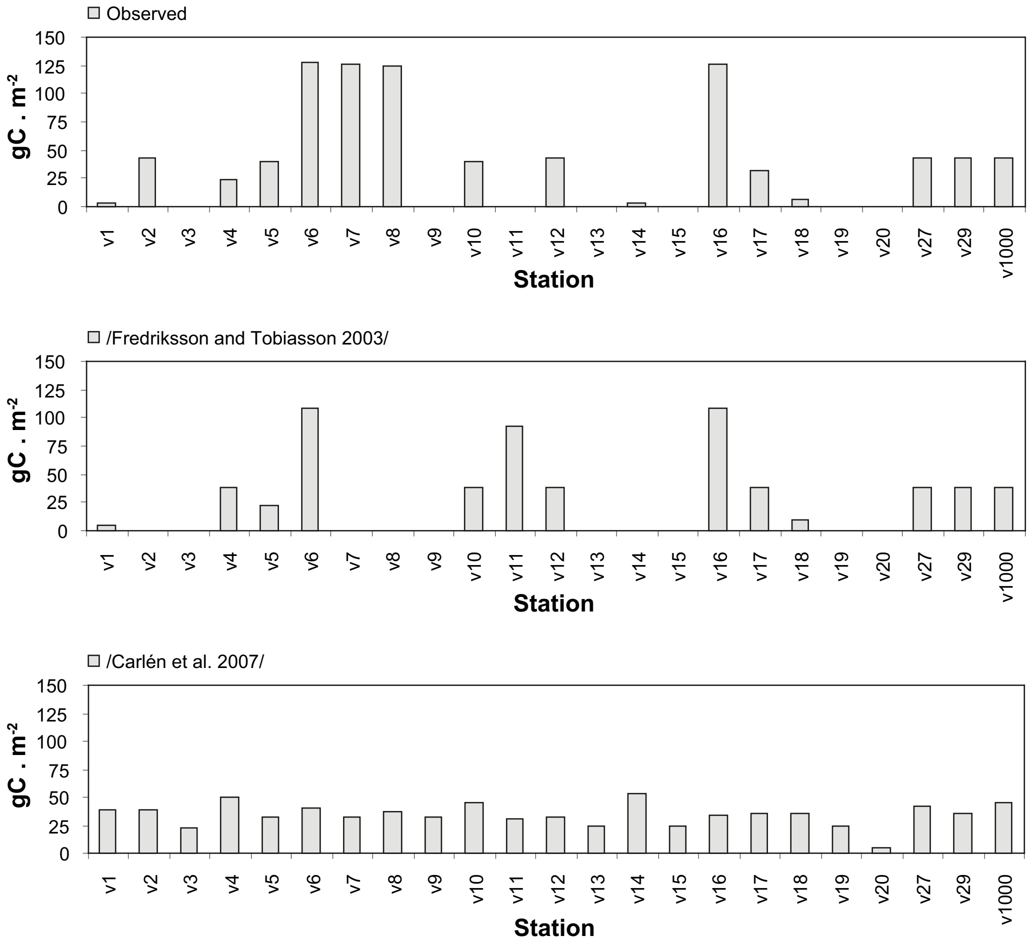

Figure 4-10. *a) Observed total vegetation biomass (gC/m²) compared to b) modelled biomass by /Fredriksson and Tobiasson 2003/ and c) /Carlén et al. 2007/.*

The model by /Fredriksson and Tobiasson 2003/ gives predictions with an average error of 21 gC m^{-2}, resulting in a NRMSE of 0.34, whereas the model by /Carlén et al. 2007/ gives predictions that are deviating with 31g C m^{-2} from observed values, also resulting in a NRMSE of 0.34. The correlation coefficients are the usually low (with cover data for specific *Chara spp.* being more accurate, see Table 4-1), indicating the inability of the models to predict values at specific sites. The model by /Carlén et al. 2007/, again, giving the lowest values.

As the state variable modelled in the safety assessment program is biomass on a basin scale, it is appropriate to validate the performance of the two vegetation models at this scale too. Figure 4-11 shows such a compilation. Each bar shows average biomass coverage (gC/m^2) from all investigated sites within each of the three basins that make up the study area. Data from the models are used the same way: only data from the same sites are used in this compilation. No further statistic measures has been made as the sample size is far too small (three basins) to make sense. The eyes may be better judges in this case. As seen in the right margin "All sites", both models seem to underestimate vegetation biomass to some degree. The model by /Tobiasson and Fredriksson 2007/ do this in all individual basins, as well, whereas the model by /Carlén et al. 2007/ (in press) is less biased. However, it does not seem to be more accurate. Both models have far better predictability than for individual sites (Figure 4-8). For Borholmsfjärden, where most sites where investigated, both models underestimate biomass by more than 30%. The best fit is at Sketuddsfjärden, where both models produce an 8% error, but this is only based on four investigated sites. Granholmsfjärden seems to be the most difficult basin to model, as both models produce highly incorrect estimates. Whether this predictability produces acceptable data for future safety modelling is of course dependent on the level of resolution in the final model.

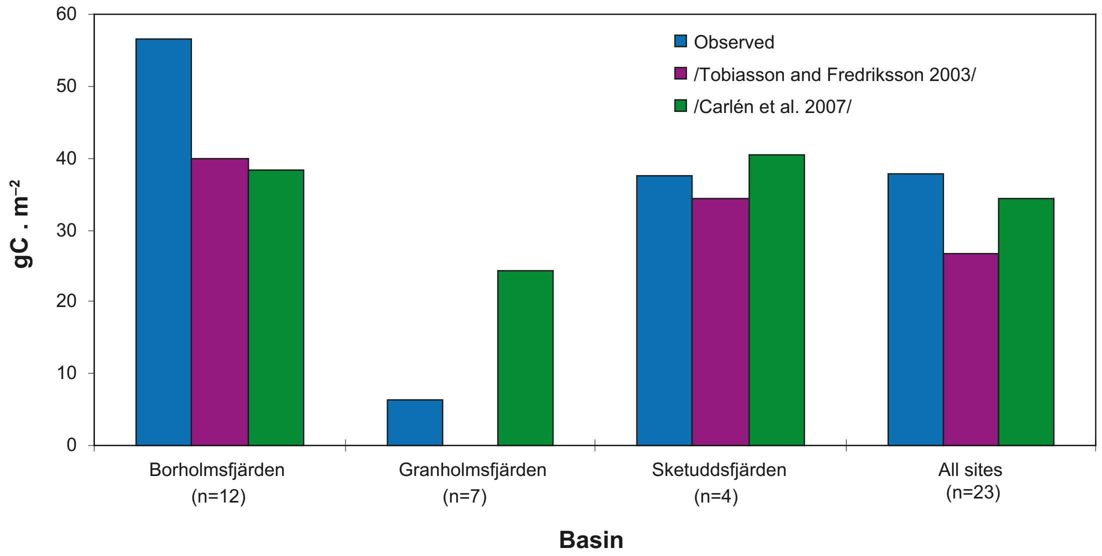

Figure 4-11. *Average observed total vegetation biomass (gC/m^2) from all investigated sites within each basin, compared with modelled results at the same sites.*

4.3 Summary

It could not be proved that any of the models produced biased data, i.e. a constant over- or underestimation of vegetation types. Both models produced results with a low correlation (and in two cases no correlation) to observed values (correlation coefficient shown as r^2 values in Table 4-1 to 4-3). Partly, this may be explained by the fact that vegetation was found to be very patchy. Either a specific type of vegetation dominated the area, or it was more or less absent. Nevertheless, the predictability of both models on vegetation type and biomass (coverage) at individual sites is not impressive. The fit between modelled data and observed data was better for /Fredriksson and Tobiasson 2003/ than for /Carlén et al. 2007/. The reason for this is that the model by /Fredriksson and Tobiasson 2003/ is basically an interpolation of previous vegetation samples from the area. The model by /Carlén et al. 2007/ is made from correlation between vegetation observations and spatially distributed physical properties and lacks detailed predictability in the area. This model is however more useful for predictions outside the investigated area.

The actual vegetation at a specific site is to a certain degree dictated by the previous history of that spot and also by other factors that may be considered random variables or at least not physically dictated. This means a large portion of randomness, creating a patchiness of vegetation cover that any model is unable to predict. (Although it may be quite possible to simulate a similar patchiness of vegetation, it will not give more accurate results.) Given this situation, the model predictions by /Carlén et al. 2007/ for vegetation cover at specific sites may be interpreted (at first hand) as the relative probability of finding a specific vegetation type at that site.

The major restriction with the model by /Fredriksson and Tobiasson 2003/ is the restriction of the model to current conditions. If the model is to be used for estimates of future ecosystems within the time regimes used in the SKB safety assessment, it will not be able to adapt to future conditions. This means it will not be able to take into account that a particular basin contains a specific assembly of macrophytic species because of e.g. its relative distance to a freshwater outlet or influence of water exchange with the open sea. If the coastline changes, the vegetation at a specific grid point will still be modelled by an interpolation of the current vegetation at its´ most proximate sampled sites (as sampled by /Fredriksson and Tobiasson 2003/), regardless of what conditions will be at those sites at the modelled time period. The model by /Fredriksson and Tobiasson 2003/ does work well for predicting current vegetation but it is constrained in geographical and temporal conditions. Future researchers need to keep these restrictions in mind, since the model was not designed for such use.

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Appendix 1

Primary data from field survey 22–23 August 2007

Site	Coordinates (RT 90)		Depth (m)	Substrate	Estimated cover (%)		
	X	Y			*Chara spp.*	*Phanerogames*	*Vaucheria spp*
v1	1551723	6367752	1.5	gyttja	1	10	0
v2	1549329	6369004	0.5	dy	100	0	0
v3	1552024	6369191	6.0	lös dy	0	0	0
v4	1552120	6368143	2.0	gyttja	5	75	0
v5	1552223	6368188	1.0	gyttja/dy	90	0	0
v6	1551026	6367178		gyttja	0	15	100
v7	1551456	6367307		gyttja/dy	0	10	100
v8	1551355	6367099	3.7		0	0	100
v9	1550966	6368619	7.0	dy	0	0	0
v10	1550972	6367020	2.0	gyttja	80	20	0
v11	1551940	6367404	6.0	block, dy	0	0	0
v12	1551951	6368364	2.0	gyttja	100	0	0
v13	1551465	6368723	5.0	block	0	0	0
v14	1551722	6368154	0.4	gyttja	7	0	0
v15	1550956	6368466	6.0	dy	0	0	0
v16	1551042	6367217		gyttja	0	10	100
v17	1550405	6368149	1.0	gyttja	65	15	0
v18	1551709	6367634	3.0	gyttja/dy	0	20	0
v19	1551250	6368713	7.5	dy	0	0	0
v20	1552281	6369268	13.0	dy	0	0	0
v27	1550327	6367918	1.5	gyttja	100	0	0
v29	1550452	6367696	1.8	gyttja, lera, enstaka b	100	0	0
v1000	1552148	6368113	2.0		100	0	0