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## NOTE

# NON-DESTRUCTIVE SAMPLING OF *SCHOENOPLECTUS MARITIMUS* IN SOUTHERN FRANCE

Christophe Gouraud[1,2,3], Jean-François Giroux[1], François Mesléard[2], and Laurent Desnouhes[2]
[1]*Département des Sciences Biologiques*
*Université du Québec à Montréal*
*P.O. Box 8888, Station Centre-ville*
*Montréal, Québec, Canada, H3C 3P8*

*Corresponding author e-mail: giroux.jean-francois@uqam.ca*

[2]*Centre de recherche pour la Conservation des zones humides méditerranéennes, Tour du Valat*
*Le Sambuc F-13200 Arles, France*

[3]*Present address:*
*Domaine de Jarras - Listel*
*F-30220 Aigues - Mortes, France*

*Abstract:* Above- and belowground biomass of the macrophyte *Schoenoplectus maritimus* was measured in Camargue (Rhône delta, southern France) using destructive and non-destructive sampling methods. Our aim was to validate whether non-destructive sampling could be used for long-term monitoring of marshes subjected to grazing by cattle and Greylag geese (*Anser anser*). Height and diameter explained more than 95% of the variation in shoot biomass but the allometric models differed between 2002 and 2003 for the grazed marsh and between the grazed and ungrazed marshes in 2003. This indicates that a generalized model could not be derived and that specific models would have to be established for each marsh. However, we determined that sampling 20 shoots per marsh would be sufficient to establish accurate models. Allometric models underestimated aboveground biomass obtained by destructive sampling and we thus computed correction factors. Total belowground biomass was adequately predicted by the aboveground biomass although the precision of the relationship varied between marshes and years. We concluded that non-destructive sampling can be used to estimate biomass of *S. maritimus* but that the technique must be adjusted for each study.

*Key Words:* aboveground biomass, allometric models, belowground biomass, herbivory

## INTRODUCTION

Harvesting of plant material is typically used to estimate primary production of macrophytes in wetlands. Destructive sampling, however, is often inaccurate in tidal environments (Shew et al. 1981), estimates are highly variable (Hopkinson et al. 1978), or production is underestimated (Odum and Smalley 1959, Milner and Hughes 1968). It is also labor intensive and thus costly. Finally, harvesting is not always a feasible strategy in long-term monitoring that aims, for instance, at tracking the cumulative effects of herbivores on macrophyte biomass.

Non-destructive techniques offer an alternative to study biomass production (Hopkinson et al. 1978, Hardisky 1980, Lieffers 1983, Giroux and Bédard 1988, de Leeuw et al. 1996, Thursby et al. 2002). Non-destructive sampling can also be labor intensive and is sometimes unsuitable (Dickerman et al. 1986). However, when based on strong relationships between morphometric parameters and shoot biomass, allometric equations can yield accurate estimates of aboveground biomass (Nixon and Oviatt 1973, Gross et al. 1991, Teal and Howes 1996). Destructive sampling of belowground biomass is even more labor intensive and often greatly disturbs study sites. Establishing relationships between above- and belowground biomass can be an alternative way to estimate belowground biomass without harvesting underground plant material (Giroux and Bédard 1988).

Sea club-rush (*Schoenoplectus maritimus*) is a common clonal macrophyte in brackish temporary wetlands with a widespread distribution in temperate zones (Lieffers and Shay 1982, de Leeuw et al.

1996, Charpentier et al. 1998). It is a very nutritious plant and herbivores consume both its above- and belowground parts (Pehrsson 1988, Esselink et al. 1997). Release of buds from dormancy due to rhizome severing may alter resource translocation among tubers with consequences for subsequent aboveground growth (Charpentier et al. 1998). Temporary marshes are characterized by annual variation in water levels and salinity, which also can directly affect *S. maritimus* growth (Lieffers and Shay 1982). How these factors affect the relationship among morphology, biomass and shoot-root ratio is unknown.

We sought to determine whether non-destructive sampling using allometric relationships could accurately estimate above- and belowground biomass of grazed and ungrazed *S. maritimus* in marshes of the Rhône delta in southern France. This was part of a larger study that evaluated the long-term effects of herbivores (cattle and Greylag geese *Anser anser*) on the production and resource allocation of *S. maritimus*. We developed several allometric models to account for annual variation in environmental conditions and the potential effects of herbivores. We validated the allometric models by comparing biomass estimates with those obtained by destructive sampling.

## METHODS

### Study Site

Our study was conducted at the Tour du Valat Nature Reserve (43°30′ N, 04°30′ E) located in the Camargue region of southern France. This 1,071-ha reserve is characterized by a large number of shallow brackish marshes ranging in size from $< 100$ m$^2$ to several hectares. We focused our experiments in the St-Seren (70 ha) and Manche Nord des Relongues marshes (28 ha) (Figure 1). Vegetation is dominated by *Schoenoplectus maritimus*, which covers more than 50% of the marshes. Other species include *Phragmites australis*, *Schoenoplectus litoralis*, *S. lacustris*, *Typha latifolia*, *T. angustifolia*, *Paspalum paspalodes*, and *Juncus gerardi*. The St-Seren marsh is grazed by cattle from April to October (0.5 bovine animals per hectare) to control growth of emergent vegetation. It also supports a large number of wintering Greylag geese, estimated at 54,000 goose-days between 1997 and 2002, with a peak at nearly 75,000 goose-days during winter 2001–2002 (Desnouhes et al. 2003). The Manche Nord des Relongues marsh is unused by herbivores in summer and is not visited by geese in winter. Water levels in both marshes are determined by autumn rains and by pumping water from adjacent canals; management ensures a short summer dry period before reflooding at the beginning of August. In 2003, water levels were higher in the St-Seren marsh for January and February and lower in July when compared with the previous year. Water levels were consistently lower in the Manche Nord des Relongues than in the St-Seren. Salinity in the St-Seren marsh was higher in 2003 (1‰–13‰) than in 2002 (2‰–6‰), particularly in July.

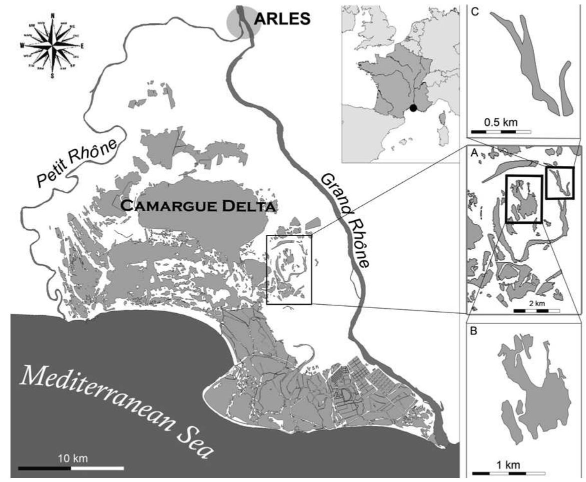


Figure 1. Location of the study site in Camargue, southern France showing A) the Voluntary Nature Reserve of Tour du Valat, B) the St-Seren marsh, and C) the Manche Nord des Relongues marsh.

### Allometric Relationships

We sampled 115 and 120 shoots in the St-Seren marsh in mid July 2002 and 2003, and 60 shoots in the Manche Nord des Relongues marsh in 2003. Shoots were randomly selected by walking in the marsh perpendicular to the shore, stopping at predefined regular intervals and picking the nearest one. We measured height of each shoot with a ruler ($\pm$ 1 mm) and diameter at ground level with a caliper ($\pm$ 0.1 mm). In 2002, we recorded whether the shoots had been grazed or not, while in 2003 we also counted the total number of leaves, the number of grazed leaves, and noted the presence/absence of inflorescence. Shoots were then cut at ground level, washed, dried at 70°C for 48 h, and weighed. Morphometric parameters were integrated into a multiple regression model to establish the best allometric equation for each sample. We used covariance analyses (ANCOVA) to examine the influence of year and marsh on the slope and intercept of the allometric equations. We further tested the effect of grazing by comparing the equations established for grazed and ungrazed shoots using ANCOVA. Additional allometric mod-

Table 1. Shoot height and diameter of *Schoenoplectus maritimus* measured in the St-Seren and Manche Nord des Relongues marshes, France, 2002–2003.

| | | | Shoot height (cm) | | | Shoot diameter (mm) | | |
|---|---|---|---|---|---|---|---|---|
| Marsh | Year | N | Mean ± SE | Min | Max | Mean ± SE | Min | Max |
| St-Seren | 2002 | 115 | 43.3 ± 2.3 | 6.2 | 114.6 | 4.7 ± 0.2 | 1.1 | 11.6 |
| St-Seren | 2003 | 120 | 60.2 ± 2.3 | 3.0 | 115.1 | 5.0 ± 0.2 | 0.8 | 12.2 |
| Manche Nord des Relongues | 2003 | 60 | 48.7 ± 3.4 | 8.0 | 93.3 | 5.3 ± 0.3 | 0.7 | 13.9 |

els were developed based on random sub-samples of 20, 40, and 60 shoots and compared with equations from the full data set using ANCOVA. Knowing the minimum number of shoots to sample for establishing an allometric relationship can minimize sampling effort. Growth parameters were log transformed (Sokal and Rohlf 1995). Because conversion of logarithmic estimates of the mean and the variance back to arithmetic units induces a systematic underestimation, a correction was made by adding half the mean square of the residuals to the intercept (Baskerville 1972).

We validated biomass estimated by non-destructive sampling by comparing biomass estimates derived from allometric equations with biomass that was harvested (Giroux and Bédard 1988, de Leeuw et al. 1996, Daoust and Childers 1998, Thursby et al. 2002). In 2003, 24 sampling stations were located in the St-Seren marsh (grazed by cattle and greylag goose) and 12 in the Manche Nord des Relongues marsh (ungrazed). Station numbers reflected the relative size of each marsh. The stations were located using a GPS and a set of random coordinates generated with a geographic information system. Sampling was conducted when *S. maritimus* biomass reached its peak at the end of July (Podlejski 1981). We measured height, diameter at ground level, number of grazed and ungrazed leaves, and presence of inflorescences on each shoot found in 15 cm × 15 cm quadrats. Aboveground biomass of each quadrat was determined by adding the estimated mass of each shoot using the allometric equations. Vegetation was harvested by clipping at ground level, washed to remove soil particles, dried at 70°C for 48 h, and weighed. Paired t-tests were performed for each marsh to compare biomass estimated by non-destructive and destructive sampling. Finally, a linear regression between these two estimates was used to correct the non-destructive sampling.

### Relationships between Above- and Belowground Biomass

Destructive sampling of belowground parts was conducted by sampling 15 cm × 15 cm × 15 cm sediment cores at the same locations as those sampled to validate the non-destructive sampling of aboveground vegetation. For each core, a sub sample of tubers (≈25%) was randomly selected to measure their dry mass (g/m$^2$, ± 0.01 g). Portions of shoots contained in the sediments were added to the aboveground biomass. The relationship between destructive above- and belowground biomass was established to determine belowground biomass without destructive sampling (Whigham and Simpson 1978, Podlejski 1981). We used ANCOVA to compare relationships between above- and belowground biomass between marshes and years. Data were analyzed with JMP IN 5.0 SAS Institute (Sall et al. 2001). Unless otherwise indicated, error values represent ± 1 SE and statistical significance was established at 5%.

## RESULTS

### Spatial and Temporal Variation in Shoot Characteristics

Shoots collected in the St-Seren marsh were taller in 2003 than in 2002 (Table 1; $t_{233} = 5.2$, $p < 0.001$). Similarly, shoots sampled in 2003 in the St-Seren were taller than those collected in Manche Nord des Relongues ($t_{178} = 2.7$, $p = 0.006$). No difference in shoot diameter was observed between marshes or years ($p > 0.05$).

### Allometric Relationships

The allometric equations for both marshes and the two years were highly significant ($p < 0.001$) and explained > 95% of the variation in shoot biomass (Table 2). All morphometric parameters were significant; however, shoot height ($p < 0.001$) and diameter ($p < 0.001$) were the most important in all models. Adding the number of leaves, the presence of inflorescences, or grazing increased $R^2$ by at most 0.02 in any model. These variables were thus not retained in the final models to minimize data collection in the field. Covariance analyses showed an effect of year (intercept effect, $F_{1,\ 229} = 215.0$, $p < 0.001$) and marsh type (slope effect associated

Table 2. Allometric equations relating dry aboveground mass (A, g), shoot height (H, cm) and shoot diameter (D, mm) of *Schoenoplectus maritimus* sampled in the St-Seren and Manche Nord des Relongues marshes, 2002–2003.

| Marsh | Year | Equation | $R^2$ | N | p | $s^2$ |
|---|---|---|---|---|---|---|
| St-Seren | 2002 | $A = e^{(-6.748 + 1.209 \ln H + 1.040 \ln D)}$ | 0.954 | 115 | $< 0.0001$ | 0.063 |
| St-Seren | 2003 | $A = e^{(-6.500 + 1.322 \ln H + 0.907 \ln D)}$ | 0.966 | 120 | $< 0.0001$ | 0.055 |
| Manche Nord des Relongues | 2003 | $A = e^{(-7.047 + 1.482 \ln H + 0.862 \ln D)}$ | 0.960 | 60 | $< 0.0001$ | 0.071 |

with height, $F_{1, 174} = 4.5$, $p = 0.034$), preventing us to use a generalized equation to explain aboveground biomass of *S. maritimus* shoots. However, the equations established for grazed and ungrazed shoots did not differ ($F_{5, 119} = 1.4$, $p = 0.231$). For a given height and diameter, shoots in the St-Seren marsh were much heavier in 2003 than in 2002, whereas the difference between the two marshes in 2003 was less important.

The lack of a generalized allometric equation means that one must harvest a sample of plants each time biomass is estimated using non-destructive sampling. We thus attempted to determine the minimum number of shoots needed to sub sample the harvested shoots. Covariance analyses showed that the number of shoots used to establish the models did not influence the allometric relationships in grazed ($F_{3, 228} = 0.4$, $p = 0.789$) and ungrazed marshes ($F_{2, 111} = 0.1$, $p = 0.916$). Moreover, biomass estimated by non-destructive sampling was not affected by the number of shoots used ($F_{3, 88} = 1.7$, $p = 0.164$ and $F_{2, 30} = 2.3$, $p = 0.116$ for grazed and ungrazed marshes in 2003, respectively). Consequently, sampling 20 shoots would be appropriate to derive specific allometric relationships for a marsh in a given year.

Biomass estimated by non-destructive sampling was lower than that obtained by destructive sampling for both grazed ($t_{23} = 4.4$, $p < 0.001$) and ungrazed marshes ($t_{11} = 6.0$, $p < 0.001$) studied in 2003. By computing a regression equation using estimates obtained by the two methods, it is possible to correct the non-destructive sampling estimates. The regression lines derived for each marsh did not differ (ANCOVA, $F_{1, 32} = 0.1$ and $p = 0.738$) allowing the use of a single generalized model (Figure 2). Non-destructive sampling underestimated biomass, especially for low values, as departure from the theoretical line slightly but significantly increased at lower values. We explored the effect of submersion duration and herbivory as indexed by the proportion of grazed leaves in each quadrat using a multiple regression to model the difference in biomass estimates between the destructive and non-destructive sampling methods. None of these variables explained the observed difference ($p > 0.05$).

## Relationships between Above- and Belowground Biomass

Total belowground biomass could be predicted from aboveground biomass obtained by destructive sampling (Figure 3). The relationships were very reliable in 2002 for the grazed marsh, but less so in 2003 for both types of marshes. There were differences between years and marshes for the relationships between aboveground biomass and total belowground biomass (year: $F_{1, 30} = 11.5$, $P = 0.002$ and $F_{1, 30} = 22.2$, $P < 0.001$ for slope and intercept effects, respectively; marsh: intercept effect, $F_{1, 32} = 35.0$, $P < 0.001$). Given the same aboveground biomass, we estimated a greater belowground biomass in the grazed St-Seren marsh than in the ungrazed Manche Nord des Relongues marsh. In the St-Seren marsh the annual difference was accentuated with the increase in aboveground biomass but was negligible for values lower than 250 g/m$^2$. Tuber biomass (T) represented 53%–64% of the total belowground biomass (B) and both were strongly correlated (St-Seren, 2002: $B = 490 + 1.522\,T$, $F_{1,8} = 412.1$, $R^2 = 0.98$, $p < 0.001$; St-Seren, 2003: $B = 1{,}150 + 1.085\,T$, $F_{1,22} = 64.9$, $R^2 = 0.75$,

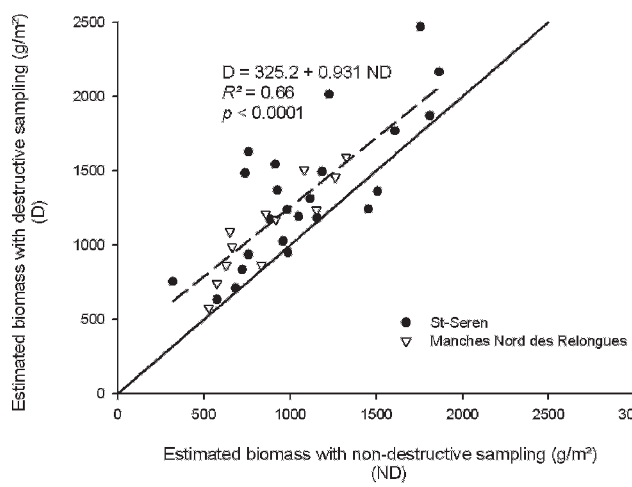


Figure 2. Relationship (dashed line) between biomass estimates *Schoenoplectus maritimus* obtained with non-destructive and destructive sampling in the St-Seren (grazed) and Manche Nord des Relongues (ungrazed) marshes in 2003. Solid line represents the theoretical model where ND = D.

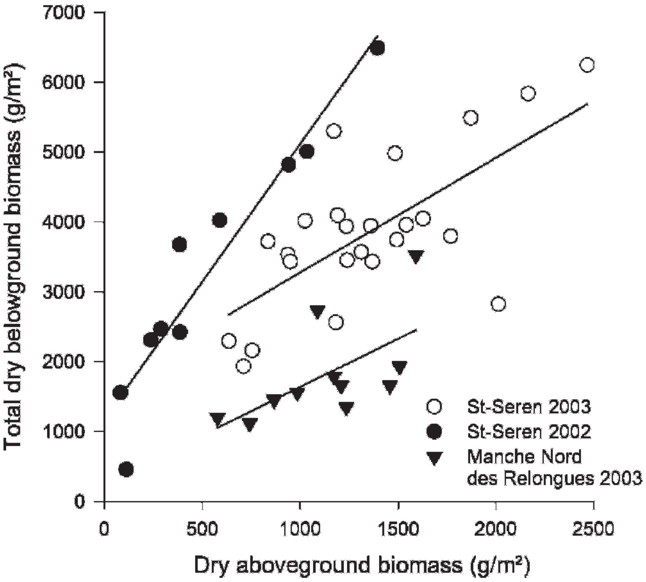


Figure 3. Relationship between dry aboveground biomass (A) and dry total belowground biomass (B) of *Schoenoplectus maritimus* (St-Seren, 2002: B = 1,178 + 3.932 A, $R^2 = 0.90$, $F_{1,8} = 75.7$, $p < 0.001$; St-Seren, 2003: B = 1,631 + 1.643 A, $R^2 = 0.48$, $F_{1,22} = 20.3$, $p < 0.001$; Manche Nord des Relongues, 2003: B = 256 + 1.380 A, $R^2 = 0.40$, $F_{1,10} = 6.7$, $p = 0.027$).

$P < 0.001$; Manche Nord des Relongues, 2003: B = 166 + 1.428 A, $F_{1,10} = 706.8$, $R^2 = 0.99$, $P < 0.001$).

## DISCUSSION

Allometric relationships differed between years and marshes for the aboveground parts of *Schoenoplectus maritimus*. The structure of the plant tissues or the cell contents must have been different during these two years as shoots in 2003 were heavier than shoots of the same height and diameter in 2002. We hypothesize that the increased biomass of plants collected in the St-Seren marsh in 2003 was driven by different water levels or salinity. Barclay and Crawford (1982) reported that higher water levels (i.e., anaerobiosis) increased shoot height without affecting *S. maritimus* dry mass. Underwater photosynthesis can affect total dry matter production in *S. maritimus* during spring growth. During the submerged period, the stored carbohydrates decrease with time but the ability of *S. maritimus* to emerge from deep water is not affected (Clevering et al. 1995). Higher water levels at the beginning of the growing season may have resulted in taller shoots in the St-Seren marsh in 2003 than in the previous year. However, lower water levels during the second part of the growing season may have enhanced photosynthetic activity yielding heavier shoots. Plant production can also be affected by temperature, light, nutrient content, and canopy-air $CO_2$ concentration (Plus et al. 2001, Rasse et al. 2002). However, we did not measure any of these parameters and therefore cannot determine their importance in explaining the observed differences in the allometric relationships.

Non-destructive sampling underestimated biomass especially at low values. This underestimation contrasts with results of Giroux and Bédard (1988) who reported an overestimation of the biomass of *Schoenoplectus americanus* by non-destructive sampling. They proposed three potential sources of error: shoot density assessment, height estimation from a sample of shoots, and the accuracy of the allometric models. We are confident in the reliability of our counts to establish shoot density and discarded the second source because we measured all shoots in each quadrat. Model accuracy based on $R^2$ values was high but not all variables were included in the models. The number of leaves, for instance, did not significantly increase $R^2$, but omitting this parameter may have contributed to underestimating aboveground biomass. On the other hand, we showed that grazing and duration of submersion had no effect on the difference in biomass estimates between non-destructive and destructive sampling.

Hydrological conditions observed in 2002 and 2003 were sufficiently different to affect *S. maritimus* growth. This could explain the difference in slopes of the regressions between the above- and belowground biomass during the two years in the St-Seren marsh. In 2003, shoots had to draw more energy from tubers to emerge from water (higher water level) and to develop leaves for photosynthesis. We also found a lower total belowground biomass (for a given aboveground biomass) in the ungrazed marsh than the grazed one. We suggest that *S. maritimus* shoots allocate relatively more energy to their belowground than aboveground parts when they are grazed by geese and cattle. While foraging on tubers, geese physiologically sever rhizome chains. Charpentier et al. (1998), who studied the effects of rhizome severing on the clonal growth and architecture of *S. maritimus*, found a larger number of buds sprouting, more rhizome initiation, more tubers without aboveground shoots, a lower shoot density, and a smaller shoot biomass in severed clones than in controls.

Non-destructive sampling of *S. maritimus* in southern France is a suitable technique to estimate aboveground biomass. The technique, however, has limitations because specific allometric relationships must be established for each marsh and each year. Fortunately, a random sample of only 20 shoots per marsh is sufficient to establish accurate allometric equations. Nevertheless, correction factors are required to prevent underestimation of biomass by non-destructive sampling. Non-destructive sampling is useful to monitor the impact of environmental changes or catastrophic events, such as widespread flooding. We conclude that non-destructive sampling is an appropriate technique to quantify cumulative impact of disturbances on the primary production of *S. maritimus* dominated marshes.

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