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Mokos, Melita

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Melita Mokos

EFFECT OF SEDIMENTATION ON GROWTH AND DISTRIBUTION OF SEAGRASSES IN THE WESTERN PART OF NOVIGRAD SEA, CROATIA

Doctoral thesis

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This doctoral thesis was performed at the University of Zadar, Department of Ecology, Agronomy, and Aquaculture, under the guidance of Stewart T. Schultz Ph.D., Associate Professor, as a part of the inter-university postgraduate studies of Applied Marine Sciences at the University of Split and University of Dubrovnik.

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Contents

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Melita Mokos

Thesis performed at the University of Zadar

Abstract

Seagrass meadows are extremely important as primary producers and as a habitat. They stabilize the substrate and protect the coastline from the erosion. They have enormous potential to trap carbon from the atmosphere so they act as a carbon sink. Seagrass loss is present worldwide due to anthropogenic activities and also climate change. Sediment burial of seagrass is one of the reasons for global seagrass decline. This research used videography method to document changes in sediment accumulation, seagrass density and ground coverage in western part of Novigrad Sea in time period from 2009 to 2011. Changes found in sediment accumulation are partially responsible for changes found in seagrass ground coverage. Moreover, this research confirmed the success of the videography method fir seagrass monitoring. Analysis of seagrass samples found vertical rhizome in *Zostera marina* and *Zostera noltei* which is a unique report for *Z. marina* and second report in the world for *Z. noltei*. Vertical rhizome is probably induced by sediment burial in the studied area caused by strong E-NE winds and this morphological feature can be interpreted as a local adaptation for burial tolerance of this seagrass population. Seagrass samples collected in the area with higher sediment accumulation rate showed higher belowground biomass which indicates the development of large anchoring system to better cope with hydrodynamic activity. Data gathered through this research can help improve the management of studied Natura 2000 area.

(137 pages, 68 figures, 14 tables, 105 references, 2 appendices, original in English)

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Supervisor: Stewart T. Schultz, PhD, Associate Professor

Reviewers: 1. Dr.sc. Ante Žuljević, Research scientist
2. Dr.sc. Danijela Bogner, Research scientist
3. Dr.sc. Sanja Puljas, Research associate

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Sveučilište u Splitu, Sveučilišni Odjel za studije mora
Sveučilište u Dubrovniku
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UTJECAJ SEDIMENTACIJE NA RAST I RASPROSTRANJENOST MORSKIH CVJETNICA U ZAPADNOM DIJELU NOVIGRADSKOG MORA

Melita Mokos

Rad je izrađen na Sveučilištu u Zadru

Sažetak

Livade morskih cvjetnica iznimno su značajne kao primarni proizvođači i stanište, važan je njihov utjecaj na stabilizaciju supstrata i zaštitu obale od erozije te su vrlo učinkovite u uklanjanju CO_2 iz atmosfere te predstavljaju spremišta ugljika. Zbog sve većeg pritiska antropogenog djelovanja i klimatskih promjena, morske cvjetnice nestaju diljem svijeta. Također, zatrpavanje morskih cvjetnica sedimentom jedan je od ključnih razloga njihovog nestajanja. Istraživanje provedeno za potrebe ove disertacije koristilo je metodu videografije kojom se zabilježila neto akumulacija sedimenta te gustoća morskih cvjetnica u zapadnom dijelu Novigradskog mora i promjene u pokrovu morskog dna u razdoblju 2009. – 2011. g. Uočene promjene u akumulaciji sedimenta djelomično su odgovorne za promjene nastale u pokrovu dna morskim cvjetnicama. Također, ovo istraživanje potvrdilo je uspješnost upotrebe metode videografije za praćenje promjena naselja morskih cvjetnica. Analizom prikupljenih uzoraka morskih cvjetnica *Zostera marina*, *Zostera noltei* i *Cymodocea nodosa* otkriven je vertikalni rizom kod vrsta *Zostera marina* i *Zostera noltei* što je jedinstveni nalaz sa vrstu *Z. marina* te tek drugi nalaz u svijetu za vrstu *Z. noltei*. Vertikalni rizom je vjerojatno induciran zatrpavanjem sedimentom uzrokovanim sjevernim i sjeveroistočnim vjetrovima, a ova morfološka osobina može se tumačiti kao lokalna adaptacija istraživane populacije morskih cvjetnica na zatrpavanje sedimentom. Uzorci morskih cvjetnica prikupljeni u području s većom stopom akumulacije sedimenta imali su veću podzemnu biomasu što upućuje na razvoj većeg "sustava sidrenja" kojim se cvjetnice pričvršćuju za dno kako bi bolje podnijele jače hidrodinamičke uvjete. Prikupljeni podaci mogu doprinijeti boljem upravljanju istraživanog Natura 2000 područja.

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Mentor: Dr.sc. Stewart T. Schultz, izvanredni profesor

Ocjenjivači:
1. Dr.sc. Ante Žuljević, viši znanstveni suradnik
2. Dr.sc. Danijela Bogner, viši znanstveni suradnik
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1. INTRODUCTION

Seagrasses are flowering plants adapted to life submerged in seawater, and inhabit soft sandy and muddy bottoms of almost all world seas (Short & Wyllie-Echeverria 1996; Short & Coles 2001; Vermaat et al. 1997). Seagrasses are important as primary producers, contributing to the base of the coastal food web and recycling nutrients that would otherwise be left unused in bottom sediments. Their role as habitat is priceless; they serve as "nursery" for vertebrates and invertebrates, stabilize the substrate, and protect the coast from erosion (Larkum et al. 2006, Orth et al. 2006) providing ecosystem services worth approximately \$30.000 ha^{-1} $year^{-1}$ (Costanza et al. 2014). Importance of this habitat has increased in recent years due to its ability to trap carbon and act as a carbon sink. This way, seagrasses remove CO_2 from the atmosphere and contribute to climate change mitigation. Though they cover less than 0.2% of oceans, seagrass beds contain approximately 10% of the yearly estimated organic carbon burial in the oceans (Fourquearan et al. 2012).

There are about 60 different seagrass species globally distributed, grouped into 13 genera and 5 families (Short & Coles 2001). They are mostly marine organisms, but some of them survive different conditions from freshwater to hypersaline (Short & Coles 2001).

Seagrass habitats have declined globally by over 30% since 1879 (Waycott et al. 2009), and ongoing losses are caused primarily by anthropogenic eutrophication and sedimentation (Walker et al. 2006; Cabaço et al. 2008). Any activity that alters local hydrodynamics or sediment mass will change local rates and directions of sediment movement and the conditions for seagrass persistence. These include any kind of coastal development (harbors, marinas, breakwaters, beach reclamation) and changes in watershed use that alter the sediment discharge rate.

Sediment dynamics are influenced naturally by both biotic and abiotic processes, occurring at a variety of spatial and temporal scales from constant wind waves, tidal currents, burrowing animals, to episodic storms, landslides, shifts between dynamic stable states, tectonic events and climate change. Such processes alter seagrass sediment habitat by changing turbidity, sediment grain size, substrate chemical and physical properties, and rates of sediment removal and deposition (Koch 2001).

These processes can eliminate entire seagrass beds through burial or erosion (Duarte et al. 1997; Manzanera et al. 1998); however, mild or gradual shifts in sedimentation can trigger adaptive developmental responses involving changes in growth and differentiation of plant modules that allow persistence of the population (Duarte et al. 1997; Frederiksen et al. 2004). Indeed, these plastic responses of plant growth are commonly assumed to be evolutionary responses to selection for tolerance of burial or erosion within the dynamic sedimentary habitat of nearly all seagrass species.

There are four seagrass species found in fully marine habitats in Croatia: *Posidonia oceanica* (Linnaeus) Delile, 1813, *Zostera marina* Linnaeus, 1753, *Zostera noltei* Hornemann, 1832 and *Cymodocea nodosa* (Ucria) Ascherson, 1870. All of these species are strictly protected under the Ordinance on Strictly Protected Species (NN 144/13).

1.1 Aim and goal of the dissertation

Despite their ecological significance, there is a lack of information about seagrass-sediment interaction of seagrass species in the eastern Adriatic, including Novigrad Sea. Main goal of this dissertation is to contribute to the knowledge about the relationship between seagrass and sediment deposition in natural conditions. This work aims to identify relationship between seagrass and sedimentation in natural environment and changes in seagrass distribution by using DGPS videography method (Schultz 2008) in combination with seagrass and sediment sampling. In addition, it aims to identify the effects of sedimentation on seagrass distribution as well as seagrass shoot density, biomass, rhizome growth forms and morphological variables (leaf length, leaf sheath length, internode length) which can indicate seagrass response to sediment burial and erosion. Seagrass habitats have declined globally by over 30% since 1879 (Waycott et al. 2009), and ongoing global seagrass losses are caused primarily by anthropogenic eutrophication and sedimentation (Short and Wyllie-Echeverria 1996; Orth et al. 2006; Walker et al. 2006; Cabaço et al. 2008). Considerable sediment dynamics which include immoderate burial or erosion are one of the main causes of seagrass loss (Cabaço et al. 2008). Additionally, this research was done on 3 out of 4 Adriatic seagrass species: *Zostera marina*, *Z. noltei* and *Cymodocea nodosa* in Novigrad Sea. Novigrad Sea is a Natura 2000 site hence the results of this research can also serve to better manage this area.

The aims of this thesis were to:

- to detect changes in seagrass cover and seagrass density;
- to detect changes in sediment deposition (accumulation, erosion);
- determine if change in seagrass cover and density relate to sediment accumulation;

- determine if seagrass biomass and different morphological variables (leaf length, leaf sheath length, internode length) will differ between different depths and coast sides and if they are correlated to sediment accumulation.

2. REVIEW OF FORMER RESEARCH

2.1. *Zostera noltei*

Species *Zostera noltei* (Figure 2.1.1.) is widely distributed in the intertidal and shallow subtidal areas of the North Atlantic (in North America and southern coast of Norway to the Mauritanian coast) and also in the Mediterranean Sea (Short & Coles 2001; Hemminga & Duarte 2000) (Figure 2.1.2.). In the Mediterranean Sea it is present in bays, lagoons, small harbors or estuaries on sandy and muddy bottom. *Zostera noltei* can form monospecific beds and mixed beds with *Zostera marina*, *Cymodocea nodosa* or an algae species such as *Caulerpa prolifera* (Forsskål) J.V.Lamouroux, 1809 (van Engeland 2010; Cunha et al. 2013; Pérez-Lloréns et al. 2014).

Figure 2.1.1. *Zostera noltei* (photo: Melita Mokos)

Figure 2.1.2. Distribution of *Zostera noltei* (International Union for Conservation of Nature (IUCN) 2010. Zostera noltii. The IUCN Red List of Threatened Species. Version 2016-3 <http://maps.iucnredlist.org/map.html?id=173361>).

Species *Z. noltei* forms dense beds in the muddy sand of intertidal areas. It can occur on intertidal flats where salinity can change from only a few ‰ to more than 30 ‰ within a few hours (Borum et al. 2004). Its leaf blades are up to 30 cm long and 0.5-1.5 mm wide (10.8 cm long and 1 mm wide, on average), with 3 longitudinal veins (Short & Coles 2001, Pérez-Lloréns et al. 2014). Species *Z. noltei* also occurs in the subtidal area although it appears to be prevailed by other seagrasses when permanently immersed (Borum et al. 2004). In many regions around the world leaves are exposed to the air during low tides, while in Novigrad Sea most of *Z. noltei* individuals are found subtidal, while only approximately 1% of the population can occasionally be found exposed to the air (personal observation).

The rhizomes are 0.5 to 2 mm thick and the rhizome segments are from 5 to 35 mm long. The youngest internodes are light green while older segments turn yellow or brown. *Zostera noltei* has 1 to 4 thin (< 1 mm) roots attached to each node between the rhizome segments (Borum et al. 2004; Pérez-Lloréns et al. 2014). Mean rhizome diameter is 1.6 mm with horizontal internode length of 12 mm in average (Hemminga & Duarte 2000). Though *Zostera* genus is reported in the past to have only horizontal rhizome, the presence of short and thin vertical rhizomes has been reported for this species by Brun et al. (2005). Leaf growth rate is high, as well as the shoot production, which represent much of the production of the species. As a small species, the modules of *Z. noltei* have a short life span, with high mortality and recruitment rates, which is typical of colonizing seagrass species (Brun et al. 2003; Pérez-Lloréns et al. 2014). The high rates of its internode production, elongation and branching allow this species to survive even under considerable disturbance (Borum et al. 2004; Cabaço et al. 2011). Hence, clonal growth instead of sexual reproduction is the main way of meadows spreading (Brun et al. 2003; Pérez-Lloréns et al. 2014.)

This seagrass species can also reproduce sexually by producing flowering shoots and seeds. Combination of both sexual and vegetative reproduction may be an excellent strategy for *Z. noltei* to survive unfavorable environmental conditions or in the establishment of new areas (Borum et al. 2004; Hemminga and Duarte 2000). Species *Z. noltei* is monoecious and it produces inflorescences in flowering shoots arising from the rhizomes (Pérez-Lloréns et al. 2014). Seeds are 1.5 to 2 mm long (Larkum et al. 2006) and mostly do not disperse far away because of its negative buoyancy (Pérez-Lloréns et al. 2014). As a part of *Zostera* genus, *Z. noltei* produces large numbers of seeds and dispersion and germination can be quite high, but only a fraction of the germinated seedlings survive to maturity (Larkum et al. 2006). Seed production and other events related to this process (flowering, seed release, dispersal and germination) are valuable to maintain genetic diversity and may be the only significant mechanism for seagrass colonization of bare sediment areas (Alexandre et al. 2006).

A protist species *Labyrinthulae sp*. can also affect *Zostera noltei* as well as *Z. marina* and can cause disease but no large-scale deterioration in *Z. noltei* meadows has been recorded. Except for *Labyrinthula*, another biological effect, bioturbation, can cause a small-scale decline in *Z. noltei*. Increased density of lugworms (*Arenicola marina* Linnaeus, 1758) covered the small shoots with layers of sediment (Philippart 1994; Townsend & Fonseca 1998; Volkenborn et al. 2007; Eklöf et al. 2015).

2.2. *Zostera marina*

Species *Zostera marina* (Figure 2.2.1.), also called eelgrass, is most widely distributed seagrass species and it dominates the area of world north temperate oceans and seas. It occurs in sandy and muddy coastal bottoms of low to moderate wave exposure in the intertidal zone to 10-15 meters depth depending on water transparency (Pérez-Lloréns et al. 2014). *Zostera marina* dominates coastal and estuarine areas of the western North Atlantic, a region considered as the Atlantic coast from Quebec (Canada) at approximately 60°N to North Carolina (United States) at 35°N. *Zostera marina* is also found in Hudson Bay, Newfoundland and Nova Scotia, although it is absent from the northern coastline of the Bay of Fundy (Larkum et al. 2006). In the Mediterranean Sea it is considered a relict species and it forms small isolated stands in shallow protected bays and coves in the northwestern Mediterranean area (Spain, France, Italy) and Adriatic Sea (Figure 2.2.2.). It is a eurythermic (−1 to 25 °C) and euryhaline (5 to 35) species (Bernard et al. 2005; Bernard et al. 2007; Sfriso & Facca 2007; Kruschel et al. 2009; Schultz et al. 2011; Silva et al. 2013; Pérez-Lloréns et al. 2014). Species *Z. marina* can form monospecific stands but often is a part of a mixed seagrass meadow (Short & Coles 2001, Larkum et al. 2006, Laugier et al., 1999; Sfriso & Facca 2007; Schultz et al. 2011; Boscutti et al. 2015).

Figure 2.2.1. *Zostera marina* (photo: Melita Mokos)

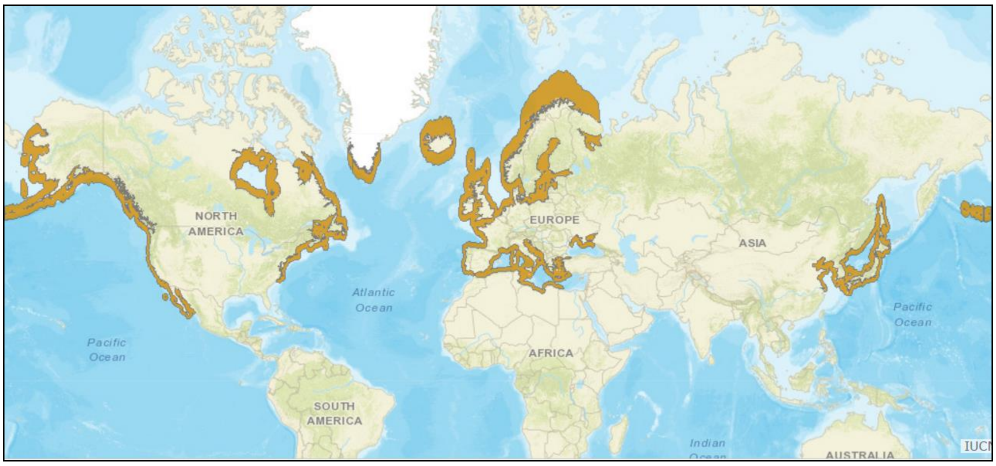

Figure 2.2.2. Distribution of *Zostera marina* (International Union for Conservation of Nature (IUCN) 2010. Zostera marina. The IUCN Red List of Threatened Species. Version 2016-3 <http://maps.iucnredlist.org/map.html?id=153538>)

Zostera marina was previously known to posses only horizontal, creeping rhizomes with 1-3 cm long internodes which are white-green in young ones to dark brown in the old ones (Short & Coles 2001, Pérez-Lloréns et al. 2014). Leaf blade can be to 3 meters long, and 3-12 mm wide with 5-11 longitudinal veins and blade apex rounded to slightly mucronate (Short & Coles 2001). Two bundles of roots arise from the nodes. The roots are thin and long covered by fine root hairs. (Pérez-Lloréns et al. 2014)

Zostera marina is a monoecious species and it produces inflorescences in shoots (flowering shoots) which are arising from long and thin stems. This species flowers frequently from spring to early autumn when seeds are produced (Jacobs & Person 1981; Curiel et al. 1997, Borum et al. 2004). Male and female flowers are found on the same individual and they are small, greenish and partly hidden in pockets within the leaf sheaths. Reproductive shoots change morphology during flowering to produce more leaf bundles separated by long, thin stem segments. When fully developed, flowering shoots detach and float away. After that, the seeds, 2-4 mm long, drop to the sediment within the bed or get dispersed. However, soon after that seeds sink as they are negatively buoyant (Borum et al. 2004). *Zostera marina* shoots produce inflorescences which can develop large numbers of seeds. After flowering and seeds production, reproductive shoots die off, therefore represents a final and terminal event for eelgrass shoots (Borum et al. 2004; Hemminga & Duarte 2000). Mediterranean *Z. marina* beds mostly spread by clonal growth (Pérez-Lloréns et al. 2014).

Zostera marina is acclimated to reduced irradiance and leaf length varies from 15-20 cm in shallow water to more than 120 cm in deep water. Species can be found on gravel as well as in mud rich in organic matter. It is in general adapted to relatively cold habitats with temperatures ranging between -1ºC in winter and approximately 25ºC in summer (Borum et al. 2004).

In early 1930's "wasting disease" caused a worldwide loss of *Z. marina*. Wasting disease was caused by infection with *Labyrinthula zosterae* Porter & Muehlstein 1991, a slime mould (Short & Wyllie-Echeverria 1996; Ralph & Short 2002; Dolch & Reise 2010). *Labyrinthula sp.* is a widespread, benign parasite of different seagrass species, and it is likely that it becomes pathogenic when it is in unfavorable environmental conditions. Large scale seagrass losses caused by *Labyrinthula* species infections have not been recorded since that time albeit it continues to impact *Z. marina* meadows at local scale sporadically (Hemminga & Duarte 2000). The wasting disease that affected *Z. marina* worldwide in the 1930s is the major natural event to have caused large-scale decline in seagrass communities. Many populations, especially along the Atlantic coasts of Europe, USA and Canada were most affected (Short & Wyllie-Escheverria 1996).

Small-scale changes in *Z. marina* can have different causes which might not always be recognized. Storms are one of the major causes of small-scale changes in shallow-water eelgrass meadows and the changes differ depending on meadow density. Patchy and sparse eelgrass meadows are generally more vulnerable and suffer greater losses during storms than do dense, uniform meadows (Borum et al. 2004).

Zostera marina has declined extensively during the last decades following eutrophication of coastal regions of Western Europe (Olensen & Sand-Jensen 1994, Borum et al. 2004).

2.3. *Cymodocea nodosa*

Species *Cymodocea nodosa* (Figure 2.3.1.) is a warm water species distributed along the Mediterranean Sea, the eastern Atlantic, from south Portugal to Senegal and around the Canary Islands (den Hartog 1970; Cabaço et al. 2010; Pérez-Lloréns et al. 2014; Larkum et al. 2006) (Figure 2.3.2.). This species does not extend further north than the southern coasts of Portugal. *Cymodocea nodosa* can be found from shallow subtidal areas to very deep waters (40-60 m) (Duarte 1991; Borum et al. 2004).

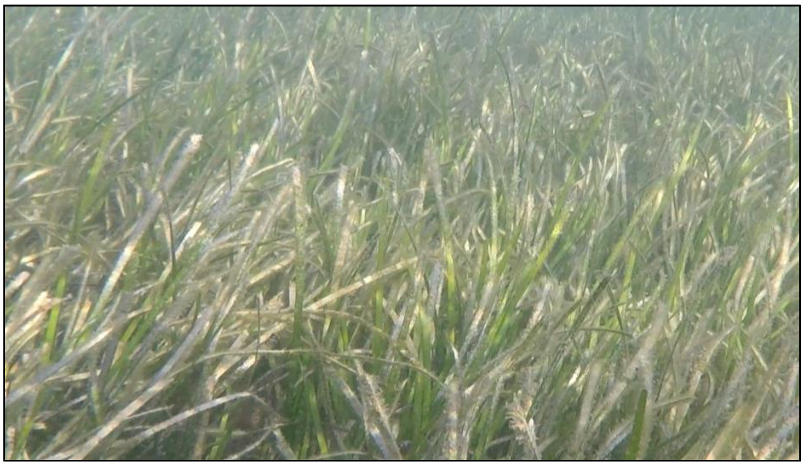

Figure 2.3.1. *Cymodocea nodosa* (photo: Melita Mokos)

Figure 2.3.2. Distribution of *Cymodocea nodosa* (International Union for Conservation of Nature (IUCN) 2010. Cymodocea nodosa. The IUCN Red List of Threatened Species. Version 2016-3 <http://maps.iucnredlist.org/map.html?id=153535>).

Species *C. nodosa* has leaf bundles consisting of 2 to 5 leaves. The leaves are 2 to 4 mm wide and from 10 to 45 cm long. The shoots are attached to vertical rhizomes with short rhizome segments which again are attached to a horizontal rhizome with 1 to 6 cm long segments. The apex forms vertical rhizomes and branches to new horizontal rhizomes. The rhizome may grow several meters per year, and *C. nodosa* is considered a pioneer species which can quickly colonize bare areas of the sea floor (Borum et al. 2004; Pérez-Lloréns et al. 2014). This species is a pioneering species and it occupies sandy and sand-muddy sediments in shallow waters down to 30 to 40 m (Green & Short 2004; Pérez-Lloréns et al. 2014). It tolerates moderate levels of physical disturbance, wide range of nutrient concentrations and reducing conditions of the sediment.

Cymodocea nodosa is a warm water species and it is tolerant to temperatures ranging from approximately 10 °C up to about 30 °C. This sensitivity to low temperature has been attributed to the tropical origin of this seagrass genus. Besides this, it tolerates salinity, withstanding fluctuations from 26 to 44 (Terrados & Ros 1995; Torquemada & Lizaso 2006; Pérez-Lloréns et al. 2014). *Cymodocea nodosa* forms both monospecific stands and mixed meadows together with *Z. noltei* (Kraemer & Mazzela 1999; Cancemi et al. 2002), *Z. marina* (Silva et al. 2013), (e.g., Venice Lagoon, Italy) or with the green alga *Caulerpa prolifera* (Perez-Ruzafa et al. 2012; Tuya et al. 2013).

Species *C. nodosa* is a fast-growing rhizomatous plant and has both horizontal and vertical rhizomes (Duarte & Sand-Jensen 1990; Marbà & Duarte 1998; Larkum et al. 2006, Pérez-Lloréns et al. 2014). Horizontal rhizome internodes are 2.1 cm long (on average) and colored white to pink. The roots are dispersed along the vertical and horizontal rhizome. Each rhizome segment only has one root which is often strongly branched and may be up to 3 mm thick and up to 35 cm long (Borum et al. 2004). Horizontal rhizomes can revert into vertical rhizomes, which terminates their horizontal growth. Vertical rhizomes can branch to produce horizontal rhizomes after the apical meristem of the original horizontal rhizome dies (Hemminga & Duarte 2000; Borum et al. 2004).

Species *C. nodosa* is a dioecious species (plants are only male or female). Flowering occurs during spring and summer and it occurs only in shoots older than 1 year, and is enhanced in response to burial. Seeds are produced at the base of mother shoots. They are negativly buoyant hence get buried close to the generative shoot (Hemminga & Duarte 2000; Green & Short 2003; Cunha et al. 2013, Pérez-Lloréns et al. 2014). Seeds germinate from April to June of the next year (Terrados 1993; Pérez-Lloréns et al. 2014).

This species growth occurs during spring and summer and it exhibits substantial plasticity, which allows this species to survive disturbances. It may occur in highly dynamic environment, for example, in migrating subaqueous dunes. In such environment it adapts to sediment burial by increasing the growth rate of vertical rhizomes (Marbà et al. 1994a). Plasticity enables *C. nodosa* to colonize unstable areas with intense sediment dynamics, such as bedforms with subaqueous dunes through its horizontal and vertical growth (Borum et al. 2004).

It occupies gravel ground as well as mud rich in organic matter. Also, it often grows in carbonate sediment with low nutrient content. Shoot mortality rates tend to increase with increasing water depth in *C. nodosa*, suggesting that it responds to light availability (Green & Short 2003; Borum et al. 2004; Pérez-Lloréns et al. 2014).

2.4. Impact of sediment burial and erosion on seagrasses

One of the factors causing widespread seagrass loss is high-energy sediment dynamics which involves burial and/or erosion. Coastal marine areas are exposed to intense sediment dynamics under the influence of storms, currents, waves, tides, etc. All mentioned effects can act on different temporal and spatial scales changing the shape of the sea bottom (Brun et al. 2005, Peralta et al. 2005). They can cause sediment movement which results in a change of seagrass habitat (Cabaço et al. 2008). Another reported cause of sediment movement is related to activities of burrowing animals (Suchanek 1983; Duarte et al. 1997). Additionally, increased sea-level rise caused by climate change can cause seagrass loss due to more frequent coastal erosion events (Short & Neckles 1999, Garner et al. 2015). Some human activities, such as coastal construction and dredging can also result in changes of sediment dynamics hence cause seagrass loss (Terrados et al. 1998; Ruiz & Romero 2003).

Such processes alter seagrass sediment habitat by changing turbidity, sediment grain size, substrate chemical and physical properties, and rates of sediment removal and deposition (Koch 2001). In the extreme, these processes can eliminate entire seagrass beds through burial or erosion (Duarte et al. 1997; Manzanera et al. 1998) or convert uninhabitable substrate to habitable by raising the elevation and insolation (Schultz et al. 2011). Seagrass decline has increased from about 1% yr^{-1} to 7% yr^{-1} (Waycott et al. 2009).

Most seagrass species inhabit soft sandy and muddy sediments which are easy to penetrate with root system. These sediments are very mobile hence currents and waves induce its transport and generate large sand ripples and sand waves making them unsuitable to support seagrass growth. These processes cause successive burial and erosion which may cause plant mortality (Hemminga & Duarte 2000).

Seagrasses respond to sediment burial and erosion in different ways and their response to sediment disturbance is species specific (Duarte et al. 1997). Tolerance to burial is higher in larger species with vertical rhizome compared to small sized seagrass with only horizontal rhizome growth which are most sensitive to burial. Seagrass response to burial is triggered by darkness (Terrados et al. 1997). An increase in the vertical internode length is a common response among species with vertical rhizomes (*Cymodocea nodosa*, *Cymodocea rotundata* Ascherson & Schweinfurth, 1870, *Halodule uninervis* (Forsskål) Ascherson, 1882, *Syringodium isoetifolium* (Ascherson) Dandy, 1939, *Thalassia hemprichii* (Ehrenberg) Ascherson, 1871) (Cabaço et al. 2008). In the absence of light, vertical internodes tend to increase their length and raise the apical meristem to the sediment surface, above the level of the horizontal rhizome with more available light and when the apical meristem reaches the sediment surface the orthotropic rhizome growth continues (Kenworthy & Schwarzschild 1998; Hemminga & Duarte, 2000; Brun et al. 2005). Furthermore, seagrass response to sediment disturbance also depends on the timing of these disturbances due to the seasonal pattern of seagrass growth (Marbà & Duarte 1994). For example, shoot growth response and survivorship to burial or erosion should be lower in winter, when *C. nodosa* grows very slowly (Marbà & Duarte 1994). Seagrass recovery after sediment disturbance depends on their ability of long term colonization capacity and patch dynamics. Changes in sediment level caused by either burial or erosion can have harmful effect on seagrasses. Effect of burial is shown as a decrease on photosynthetic area, and erosion effect as an exposure of belowground tissue of the plant (Cabaço et al. 2008). Seagrass species *Enhalus acoroides* (Linnaeus f.) Royle, 1839 is large seagrass without vertical rhizomes but it is one of the species most tolerant to burial, probably due its large leaves, which can exceed 1m in length (Cabaço et al. 2008).

Seagrasses are highly vulnerable to changes in sediment level. Previous reviews of several species showed at least 50% mortality when subject to experimental burial and most of mortality was induced by low burial levels of 2-4 cm (Cabaço et al. 2008). Large seagrass species with vertical rhizomes (*Posidonia oceanica*, *Posidonia australis* J.D.Hooker, 1858) are found to be more tolerant to burial than small seagrass with only horizontal rhizome (*Halophila ovalis* (R.Brown) J.D.Hooker, 1858, *Zostera marina*, *Zostera noltei*) (Vermaat et al. 1997; Cabaço et al. 2008). Moreover, previous studies indicate that the vulnerability of seagrasses to sediment burial decreases with increasing leaf length and rhizome diameter. The capacity to elongate vertical stems or large shoot size enabled some species to raise their leaf canopy closer to the water surface and thus suffer less in turbid water. Sedimentation rates of 2-13 cm/year can probably be coped with, depending on species (Vermaat et al. 1997).

The increase of the vertical internode length in seagrass as a response to sediment burial has been reported for a number of species in the Caribbean (Patriquin 1973, Marbà et al. 1994), the Mediterranean (Marbà & Duarte 1994; Marbà et al. 1994b) and south-east Asia (Duarte et al. 1997). After the burial, length of vertical internode may increase greatly relative to the average value. The vertical elongation rate of buried shoots increases proportionally which allows plants to survive sedimentation disturbances (Hemminga & Duarte 2000). Increased vertical growth of buried shoots is often followed by high shoot mortality. This indicates that resources reabsorbed from dead shoots may help maintain the fast vertical growth rates of the surviving shoots (Hemminga & Duarte 2000; Cabaço et al. 2008). The apical meristem of buried vertical rhizomes often branches once it reaches sediment surface to produce a horizontal rhizome that will extend over the new sediment layer (Hemminga & Duarte 2000). Some seagrass species raise vertical rhizomes above the sediment surface and position them higher in the water column hence avoiding shading by other plants present (Duarte et al. 1997; Hemminga & Duarte 2000). Some seagrass species show increased growth under low levels of sedimentation or burial (Gallegos et al. 1993, Marbà & Duarte 1994, Mills & Fonseca 2003), and some species such as *Amphibolis griffithii* (J.M.Black) den Hartog, 1970 may be specifically adapted to periodic burial (Mills & Fonseca 2003).

Seagrass shoot mortality rate increases in response to burial. However, seagrasses are expected to respond to sediment accretion by increasing shoot recruitment, since shoots surviving burial increase both vertical and horizontal branching rate. The magnitude of the response and the sensitivity of shoot recruitment and mortality rates to environmental change also depend on the species involved (e.g. response to burial). Process of recolonization depends on horizontal spread as well as on the formation of new seagrass patches from occasional seeds or vegetative fragments that may colonize the area (Hemminga & Duarte 2000; Borum et a. 2004, Cabaço et al. 2008).

Leaf morphometry of several seagrass species shows no response to changes in sediment level (*Cymodocea serrulata* (R.Brown) Ascherson & Magnus, *Cymodocea rotundata, Halodule uninervis, Enhalus acoroides*, *Halophila ovalis*, *Syringodium isoetifolium*, *Thalassia hemprichii*) (Cabaço et al. 2008). Leaf sheath length increased as a response to burial in some species (*C. nodosa*, *P. australis*) but decreased in some other seagrass species like *Z. noltei* (Cabaço &

Santos 2007), *P. oceanica* (Manzanera et al. 1998) and *P. sinuosa* (Cabaço et al. 2008). In their review on burial effects on seagrasses, Cabaço et al. (2008) found that the best predictor of the vulnerability of a seagrass species to burial is its general leaf length.

Several studies investigated the effect of erosion on seagrasses. Seagrass tolerance to erosion is also species specific and strongly associated with the size of the plant, focusing on belowground modules (rhizome and roots), which determine the anchoring depth of species. *Thalassia testudinum* K.D.Koenig, 1805 showed no response in shoot density and no response of horizontal internode length as well as no response in the number of shoots per rhizome length due to experimental erosion (Cruz-Palacios & van Tussenbroek 2005) which makes this species the most tolerant to erosion disturbance. One of the reasons explaining this strong resistance to erosion is its deep and strong anchorage system (Cabaço et al. 2008). *Syringodium filiforme* Kützing, 1860 experienced decreased shoot density when exposed to experimental erosion. Also, decrease of horizontal rhizome length was reported but only under high erosion level of 9 cm (Cruz-Palacios & van Tussenbroek 2005; Cabaço et al. 2008).

2.4.1. Effect of burial and erosion on *Zostera noltei*

Zostera noltei is a small-sized seagrass occupying intertidal and subtidal sandflats and is sensitive to burial and erosion even at low levels, previously thought to be due to lack of vertical rhizome (Cabaço et al. 2008). Duarte et al. (1997) found that the effects of burial on mortality were dependent on seagrass size. Several authors investigated the effect of erosion and burial on *Z. noltei* (Brun et al. 2005; Cabaço & Santos 2007; Han et al. 2012). Experimental evidence shows negative effects of both burial and erosion on *Z. noltei* (Cabaço & Santos 2007, Han et al. 2012). Cabaço and Santos (2007) showed that the increase of shoot mortality was a common response of *Z. noltei* to erosion and that burial threshold for 50% mortality of *Z. noltei* was 2 cm, and the threshold for total shoot loss was between 4 cm and 8 cm of burial. However, Han et al. (2012) found that the survival of *Z. noltei* was higher under burial than under comparable erosion treatments. Furthermore, survival of *Z. noltei* plants was much higher under continuous burial (94 to 100%) compared to the effect of sudden burial. This might be due to higher stress conditions that seagrass experienced during strong sudden burial (e.g. low light levels and anoxic conditions).

Additionally, Cabaço and Santos (2007) found significantly longer internodes of the horizontal rhizome were observed as a response to burial and erosion. In cases where plants were buried at deeper points, they frequently developed rhizomes without shoots when the rhizomes remained well below the preferential depth. The production of new shoots only began again when rhizomes reached the preferential depth, where shoots have access to more favorable light conditions and resume the elongation of vertical inter nodes until the apical meristem is repositioned at the sediment surface (Terrados 1997; Brun et al. 2005). Seagrass shoot density declined; however, shoot biomass did not decrease. Also, sheath length significantly decreased except in the erosion treatment where it remained high and the rhizome internode length decreased significantly along the experiment. A decrease in carbon and carbohydrates content of *Zostera noltei* rhizomes was recorded, as a consequence of the burial-induced light deficiency. Species with high storage capacity, as indicated in thicker rhizomes, are better able to survive burial disturbance. The robust relationships described indicate that the vulnerability of seagrasses to sediment burial decreases with increasing leaf length and rhizome diameter.

Cabaço et al. (2008) showed different responses of different seagrass species to burial and erosion. According to this literature source, *Z. noltei* shows following responses to sediment burial: decreased shoot density, increased horizontal internode length, no response of leaf length and sheath length, decreased leaf and rhizome carbon content in high burial levels (4 cm, 8 cm and 16 cm), decreased leaf nitrogen content and simultaneous increase in rhizomes, increased leaf sugar content in intermediate burial level of 4 cm. Responses to erosion are: decreased shoot density, increased internode length, no response of leaf length and sheath length, no response of leaf and rhizome carbon and nitrogen content, increased leaf sugar content and no response of rhizome sugar content. According to Han et al. (2012), different intensity and frequency of burial or erosion have different effects on the survival and elongation rate for *Z. noltei*.

This fast growing species is shown to be extremely sensitive to sediment burial with relatively low burial thresholds, but high horizontal elongation rate of this species allows its fast recovery after burial. *Zostera noltei* can rapidly acclimate to moderate sudden burial events and this rapid response may be enabled by the apical dominance in species, indicating that, under stress conditions, such as sudden burial, plant resources will mainly be directed to the apical shoot (Han et al. 2012).

After the passage of a sand-barrier island over *Z. noltei* meadows it took 10 years to recover through recolonization (Cunha et al. 2005). This species acclimates to burial or erosion disturbances by relocating the newly produced rhizomes to a preferential depth (from 0.3 to 0.8 cm), both in the mesocosm and field experiment; however, recovery also depends on the scale of the burial disturbance (Han et al. 2012).

Contrary to all above mentioned data, Brun et al. (2005) found vertical rhizome in *Z. noltei* which seemed to be triggered by recurrent sediment burial and erosion events. In these seagrass samples, buried vertical nodes had no shoots, vertical internodes (0.74 cm ± SEM 0.05) were shorter than horizontal internodes (2.2cm ± 0.05), and leaf sheaths were longer (10.1cm ± 0.5) than in plants without vertical rhizome (3.3cm ± 0.18). Shoots were absent from the buried nodes which may be a result of reallocation of resources to vertical growth (Hemminga & Duarte 2000). It seems that vertical growth in this species was expressed due to moderate burial while modest burial resulted in minimal vertical growth, in millimeters, and, thus, it might have not been recognized as such. Severe burial, higher than 9 cm, exceeded the vertical growth of this species. Orthotropic rhizomes of *Z. noltei* possessed numerous short internodes which is associated with low sediment accretion rates while longer internodes, which are associated with severe sediment accretion, were found closer to sediment surface until starting to grow horizontally at the sediment surface. Present difference in internodes length might indicate difference in sediment accretion rates.

Zostera noltei is very sensitive to sediment burial due to its small size, hence the maximum level of accretion or erosion tolerated by this species is extremely low.

2.4.2. Effect of burial and erosion on *Zostera marina*

It has been reported in the literature that this species does not have a vertical rhizome, hence it is highly susceptible to negative effects of sediment burial. *Zostera marina*, as well as *Z. noltei*, also experiences high mortality (70-90%) under low burial levels (Cabaço et al. 2008). *Zostera marina* is known to posses several main responses to burial conditions: increased mortality, decreased productivity, no changes in sheath length, decreased leaf length and leaf surface area (Mills & Fonseca 2003; Cabaço et al. 2008).

Mills & Fonseca (2003) experimentally buried *Z. marina* with two different sediment types: sand and silt with different levels of burial. Their results showed that the effects on plant mortality in this experiment were associated with the depth of burial and not with sediment type. Burial level as low as 25% of the aboveground plant height substantially increased mortality, with burial at this level causing the death of >75% of the plants. However, Mills & Fonseca (2003) found that addition of sand to a level of 25% of plant height (4 cm) caused slightly higher productivity. Overall, burial contributed to reduced productivity and increased mortality of *Z. marina* but this effect was not significantly influenced by different sediment types. Absence of sediment type influence might be caused by the relatively short duration of experiments. In this research *Z.*

marina showed shorter leaf length and smaller surface area in buried plants. This species appears to be sensitive to burial with the threshold level of burial tolerance being extremely low.

Munkes et al. (2015) found that *Z. marina* showed a positive net growth rate and increase in shoot density at 5 cm burial. The 5 cm treatment (~10% burial depth relative to plant height) showed higher maximum shoot density (mean: 310.4 shoots m^{-2}), when compared to the control treatment (mean: 246.4 shoots m^{-2}). Sediment burial over 5 cm led to mortality and *Z. marina* experienced density decrease when buried with 10 cm and more with substantial reduction of survival and productivity at sediment levels of 25%, and a total die-off at 75% or more of plant height. Overall, the authors concluded that negative burial effects on seagrasses depend on the leaf length of affected plants rather than general species size.

Boese et al. (2008) observed the effect of erosion on the exposure of rhizomes and roots. This influence was strongest during the winter and on the margins of seagrass bed which is consistent with some previous research (van Katwijk et al. 2000; Koch et al. 2001). This situation might prevent the establishment of stable *Z. marina* populations on the lower edge of its distribution (Boese et al. 2008).

2.4.3. Effect of burial and erosion on *Cymodocea nodosa*

Cymodocea nodosa is capable of vertical rhizome growth which enables this species to successfully cope with sediment burial, depending on the amount of deposited sediment. In the review by Cabaço et al. (2008), *C. nodosa* responds to burial with increased vertical growth rate (up to 4 cm of burial), increased length of the youngest vertical internode (up to 4 cm of burial), increased leaf sheath length (up to 4 cm of burial), increased leaf turnover rate (up to 2 cm of burial), however burial also induces increased mortality.

Marbà and Duarte (1994) showed that *C. nodosa* responded to intermediate burial (4 cm) by increasing the vertical internode length and leaf sheath length. Shoot vertical growth increased significantly with increasing burial to reach a maximum growth rate when shoots were buried with 4 cm of sediment, yet burial higher than 7 cm lead to reduced vertical growth. The increased vertical growth of shoots in response to burial < 7 cm allowed seagrass shoots to relocate their apical meristem to the sediment surface where they will have better light conditions. The length of the leaf sheaths increased from the short leaf sheaths of shoots exposed to erosion, to maximal lengths with burial of 4 cm, whereas leaf sheath length declined at greater burial depths. Increase in the vertical internode length is a common response in species with vertical rhizomes (*Cymodocea rotundata, Halodule uninervis, Syringodium isoetifolium, Thalassia hemprichii*) (Cabaço et al. 2008). According to Marbà and Duarte (1995), *C. nodosa* recovered from the burial by sand-waves by recolonization from horizontally-branching rhizomes of shoots that grew vertically to the sediment surface from the 10–20 cm burial affecting a *C. nodosa* meadow. Seagrass recovery from high loads of sediment and erosion after natural disturbances is strongly dependent on their longer-term colonization capacity and patch dynamics (Cabaço et al. 2008; Marbà & Duarte 1995). However, the proportion of surviving shoots decreases significantly as burial depth is increased, with no shoots surviving burial >7 cm. Additionally, leaf production rate and internodal length are reduced at sedimentation levels above 4 cm (Marbà & Duarte 1994).

Overall, burial has a negative influence on *C. nodosa* but moderate burial levels, to 4 cm, can have positive effects and stimulate *C. nodo*sa vertical rhizome growth and leaf growth, which is in agreement with suggestions that the growth of some other seagrass species, like *Thalassia testudinum* is stimulated by moderate burial (Gallegos et al. 1993). The ability of an established seagrass bed to cope with sediment disturbance might be higher than tolerance of experimental individual seedlings, hence established *C. nodosa* beds might possibly tolerate even higher sediment loads which could even stimulate its vertical growth (Marbà & Duarte 1994). Furthermore, there might be a difference in burial survival between the edge and the inner parts of *C. nodosa* bed with shoots within the patch having higher tolerance (Marbà & Duarte 1994).

Main responses of *C. nodosa* to erosion are: increased shoot mortality, decreased vertical internode length, decreased horizontal rhizome length, decreased vertical growth rate and decreased leaf sheath length (Cabaço et al. 2008). *Cymodocea nodosa* showed relatively low mortality when compared to other seagrass species with mortality less than 30% under erosion levels of -2 cm and -10 cm. Erosion, as well as burial, caused increased shoot mortality without survival of burial higher than 7 cm (Marbà & Duarte 1994).

2.5. Videography as a method for seagrass research

In recent decades seabed imaging methods such as optical imaging or acoustical imaging techniques have been used for direct measurements. Underwater video camera systems (Norris et al. 1997; McDonald et al. 2006) provide a direct observation of the seabed and have proved to be a good technique for habitat mapping (Lefebvre et al. 2009). Video systems can record macroalgae species composition and abundance as well as an image of the non-vegetated seabed.

Data quality can be limited by water clarity or boat speed (Lefebvre et al. 2009). Video interpretation is a time-consuming activity and subject to interpreter bias (Crawford et al. 2001). The video system provides continuous visual observation of the seabed and therefore can be used to identify seagrass species and abundance and to assess bottom type (Lefebvre et al. 2009). Many researchers used videography method to identify biodiversity and seagrass distribution (Mcdonald et al. 2006; Schultz 2008; Schultz et al. 2011; Mallet & Pelletier 2014; Vandermeulen 2014). Schultz et al. (2011) used a boat-based videography method (Figure 3.2.1.) to access the seagrass distribution data and also to detect sedimentation changes in the environment. This method has been previously shown to provide high statistical power of demonstrating seagrass cover changes of 10% or less over a 1 km^2 sampling region (Schultz 2008; Schultz et al. 2011; Schultz et al. 2015).

3. MATERIAL AND METHODS

3.1. Study area

The Novigrad Sea, Croatia (44°12'N, 15°30'E) is an estuarine embayment of 29 km^2 on the northeastern Adriatic coast receiving freshwater from the Zrmanja river and a few nearby seasonal creeks (Figure 3.1.1, 3.1.2.). It is connected to the Velebit channel to the north by the narrow Maslenica channel, and to the Karin Sea to the south by the Karin channel. Novigrad Sea is fully exposed to the bora winds and is known to experience high net sediment movement from northeast to southwest during storms, resulting in a gradual increase in bottom elevation along the western and southwestern margins over time, and in the extent of habitable lighted area for seagrass, as reflected in the geometry of the depth contours (Schultz et al. 2011). In the studied area there is a small creek Bašćica that drains approximately 25 square km of farmland and enters the estuary at its western end, a few hundred meters from the collection sites. Salinity in the study site ranges from 10 to 30 PSU (Schultz et al. 2011), and water surface temperature of the Zrmanja estuary ranges from 6.7 to 26.6 °C (Viličić 2011).

Sea bottom types include rocky bottom covered with algae, muddy and sandy ground partially covered with seagrass and gravel ground. Seagrass speciea *Zostera noltei*, *Zostera marina* and *Cymodocea nodosa* form patchy, mixed meadows on sandy or muddy substrate, with *Z. noltei* dominating at shallow depths (intertidal to 3 m), *Z. marina* at intermediate depths (1 m to 5 m) especially near freshwater sources, and *C. nodosa* in deeper habitats (3 m to 6.6 m).

The Novigrad Sea populations of *Z. marina* are completely subtidal and *Z. noltei* being in the intertidal and subtidal area. Studied area is the farthest west portion of the estuary, and most exposed to water movement caused by the E-NE bora winds over a fetch of 7-8 km, which can cause substantial sediment movement during bora storms. The closest anemometer to the study site, approximately 4.5 km distant, shows that, during an average bora, sustained 10-min wind speeds range from 10 to 20 m s^{-1}, with gusts over 60 m s^{-1} (Bajić 2003). During such storms a short-period spilling breakers of 1-2 m height and water turbid with sediment was observed (personal observation).

The transects for the videomonitoring and sampling locations were situated on the north (Posedarje) and south (natural) side of the bay (Figure 3.1.1., 3.1.2.). Northern side of the study area is populated with approx. 1300 inhabitants, without sewage treatment and sheltered from northern and northeastern winds, while the southern side of the study area is natural and not populated and it is exposed to strong bora wind.

Novigrad Sea is a part of Natura 2000 European ecological network and several habitat types important for this Natura site are located in the study area. These are:

1. sandbanks which are slightly covered by sea water all the time (Natura 2000 code: 1110)
    a. G.3.2.2.1. Association with *Cymodocea nodosa* (national classification of habitats)
2. coastal lagoons (Natura 2000 code: 1150)
    a. G.3.1.1.4. Association with *Zostera noltii* in euryhaline and eurythermal environment (national classification of habitats)
    b. G.3.1.1.5. Association with *Zostera marina* in euryhaline and eurythermal environment (national classification of habitats).

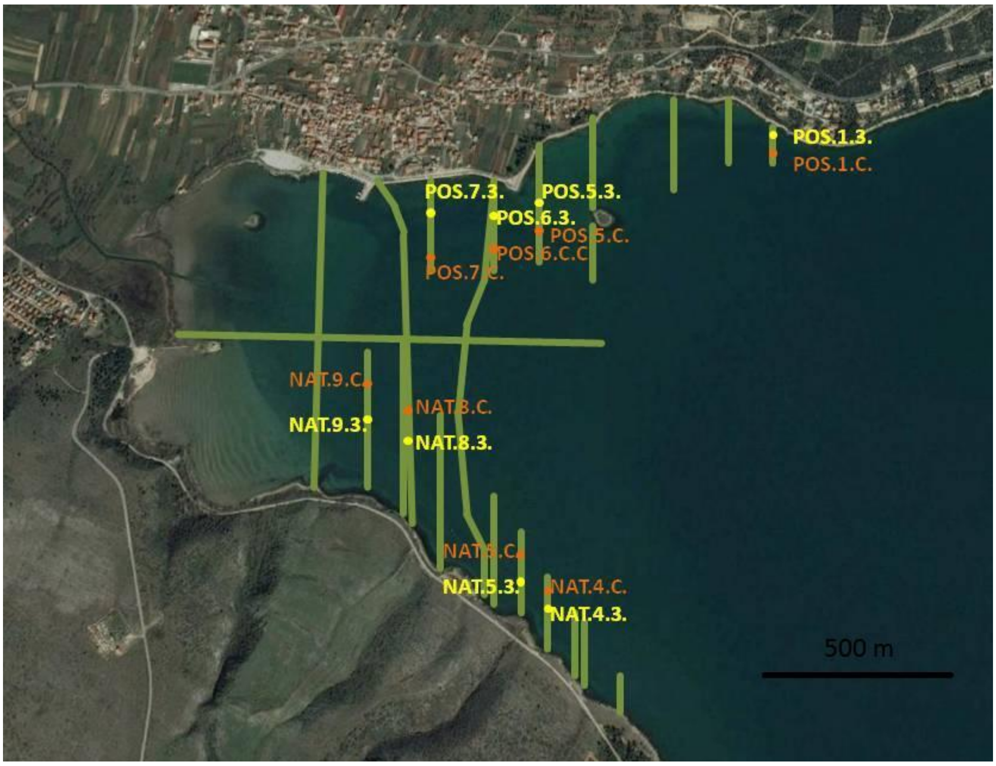

Figure 3.1.1. Map with transect positions (green lines ▬) and seagrass and sediment sampling sites (dots). Yellow dots (●) indicate locations at 3 meter depth, orange dots (●) indicate locations at 4.5 meter depth.

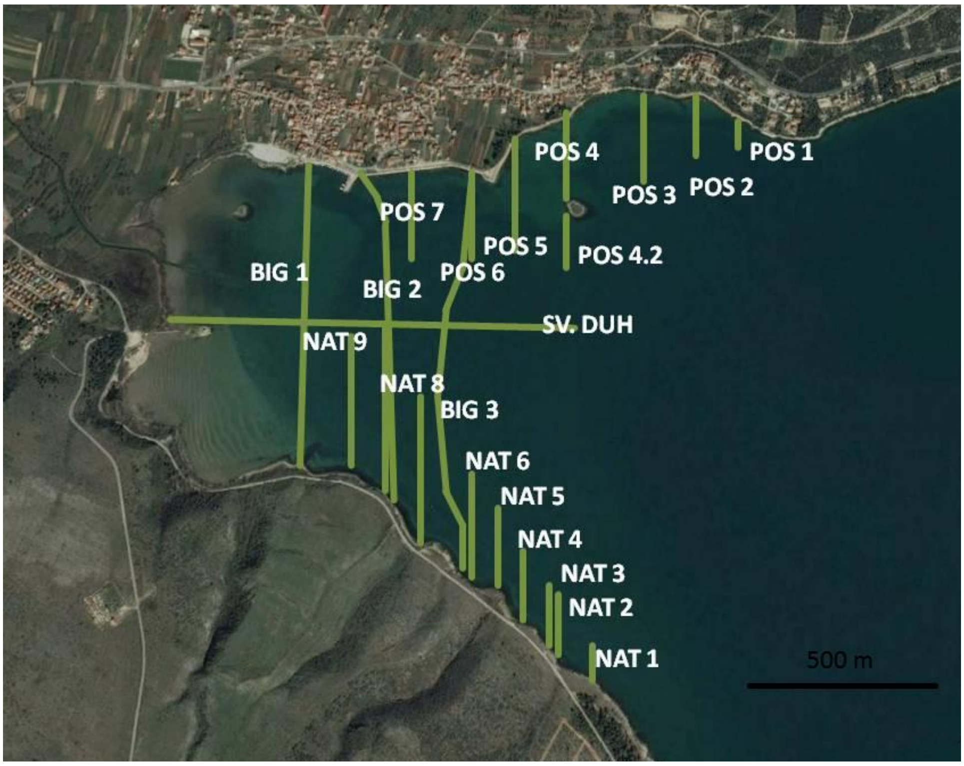

Figure 3.1.2. Map with transect positions (green lines ▬) and names of the transects.

3.2. DGPS Videography

Twenty linear transects (Figure 3.1.2.) of north-south orientation were set, from the coastline to approx. 6.6 meter depth, and monitored in June 2009, 2010, and 2011. The monitoring method followed Schultz et al. (2011), in which "monitoring was done by kayak (Figure 3.2.1.) with a video sensor which was positioned approximately 0.5 - 1 m from the bottom (Sony, 480 color TVL) and illuminated by natural daylight. The speed of kayak and sensor movement was approximately 0.5 m s^{-1}. Depth was monitored continuously and recorded every 2 seconds by a 200 KHz, 11°, single-beam transducer (precision 1%). Horizontal DGPS coordinates were taken with real-time submeter accuracy using differential correction from EGNOS satellites to a Trimble Pro-XRS receiver (Norris et al. 1997; Dauwalter et al. 2006; Schultz 2008). The GPS antenna was positioned directly above the video sensor, easily visible by the kayak operator. Trimble Pro-XRS receiver has been shown in field tests to provide distance measurements over 10 s of meters with reliability indistinguishable from that of a tape measure (Dauwalter et al. 2006). Depth was calibrated to elevation of the bottom relative to fixed reference rocks present within each transect at minimally 2 m depth. Transects were followed under calm conditions, generally winds less than 1 m s^{-1}, and the sea state was "glassy"".

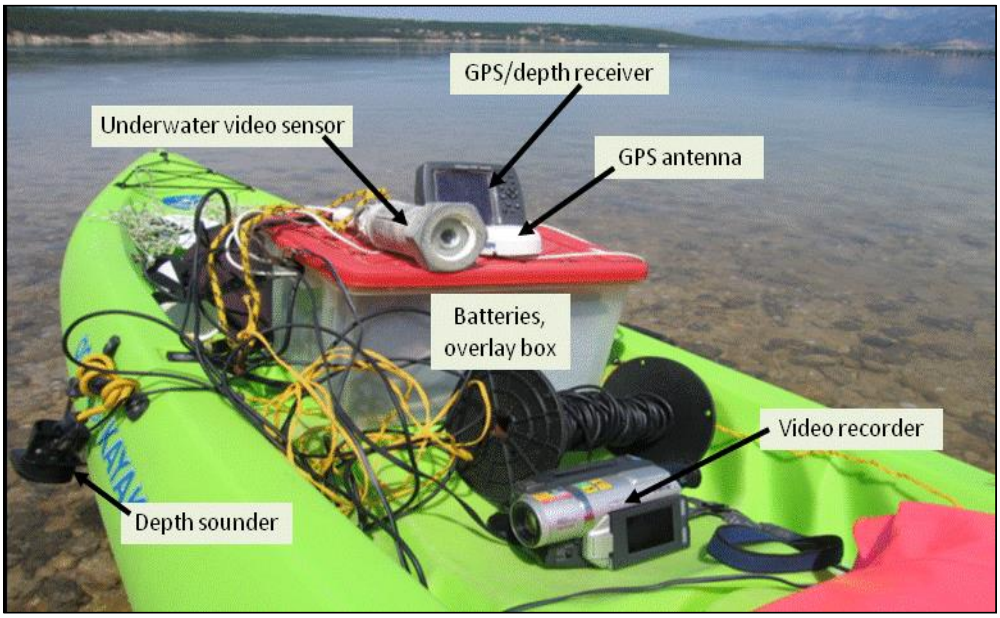

Figure 3.2.1. Kayak with the equipment for videography.

3.2.1. Video analysis

Videos recorded show ground type and ground cover together with the records of speed, depth, DGPS position, date and time (Figure 3.2.1.1.).

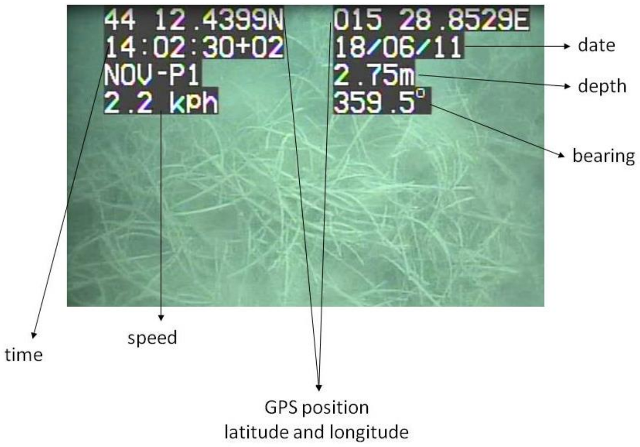

Figure 3.2.1.1. Display of the recorded video and data it shows: ground type, speed, depth, GPS position, date and time (photo: Melita Mokos).

There are several ground types determined for the analyses: rocky, unconsolidated, algae, dense seagrass and sparse seagrass (Figure 3.2.1.2.). Rocky ground varies from pebbles to boulders and unconsolidated varies from mud to gravel-rock combination (mud, sand, mixture of sand and gravel, gravel, mixture of sand and rock, mixture of gravel and rock). Analyzed surface area was c. 1 m^2. Dominant ground type, covering more than 50% of the screen was recorded for each second of the video. Seagrass density was estimated as sparse (covering less than 50% of the area) and dense (covering more then 50% of the area).

Comparing videos of two consecutive years it is possible (Schultz et al. 2011) to detect a change in seagrass coverage changing from sparse seagrass to dense seagrass and vice versa. It is also possible to detect changes in ground type as a change from unconsolidated ground to seagrass and vice versa.

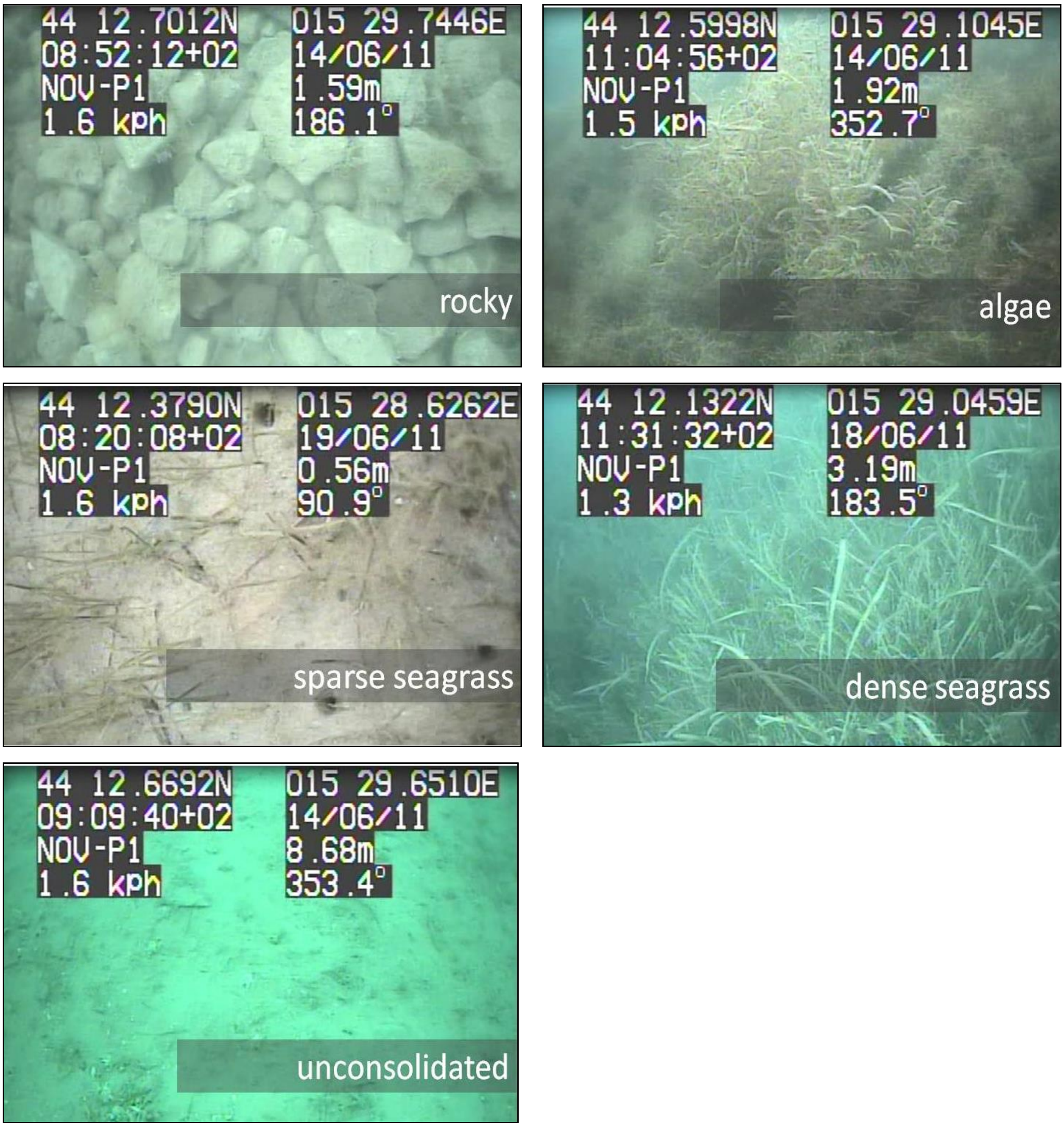

Figure 3.2.1.2. Ground types in the studied area (photo: Melita Mokos).

3.2.2. Sediment accumulation

After the video analysis, data of each transect were graphically represented as a depth profile as shown on Figure 3.2.2.1. From this plot it was possible to determine the length of transect and depth. For each transect sediment deposition and/or erosion was recorded. Sediment accumulation was calculated for each transect over the segments of bare unconsolidated sediment or a segment containing seagrass. Each transect had three versions, a version from June of the year 2009, 2010 and 2011. Sediment accumulation was measured by plotting the depth profile of the transect (cross section) of the two successive years, measuring the area between the two profiles within the seagrass and unconsolidated segments of the transect. Sediment accumulation or erosion area on the transect cross section was used as a proxy for volume of sediment accumulated or eroded on the transect. Depth profile with transect of the two successive years was laid over a millimeter paper. The number of millimeter squares between the two transects was counted and their surface was calculated. Surface calculated was the surface of accumulated/eroded sediment. From this data a net accumulation and erosion is calculated for each transect and the data of two same transects in two consecutive years were compared to each other. Gross and net sediment accumulation were tested for difference between the north and south sides of the bay (Posedarje side, natural side).

Gross sediment accumulation is the surface area of the region formed between the two transects (two lines representing the same transect in two consecutive years) displayed in longitudinal cross section on each transect over every seagrass and unconsolidated ground segment of transect. Gross sediment erosion is the surface area of the region lost between the two transects displayed in longitudinal cross section on each transect over every seagrass and unconsolidated ground segment of transect. Net sediment accumulation is the difference of accumulated and eroded sediment (gross sediment accumulation minus gross sediment erosion) and it was calculated for each transect over three years.

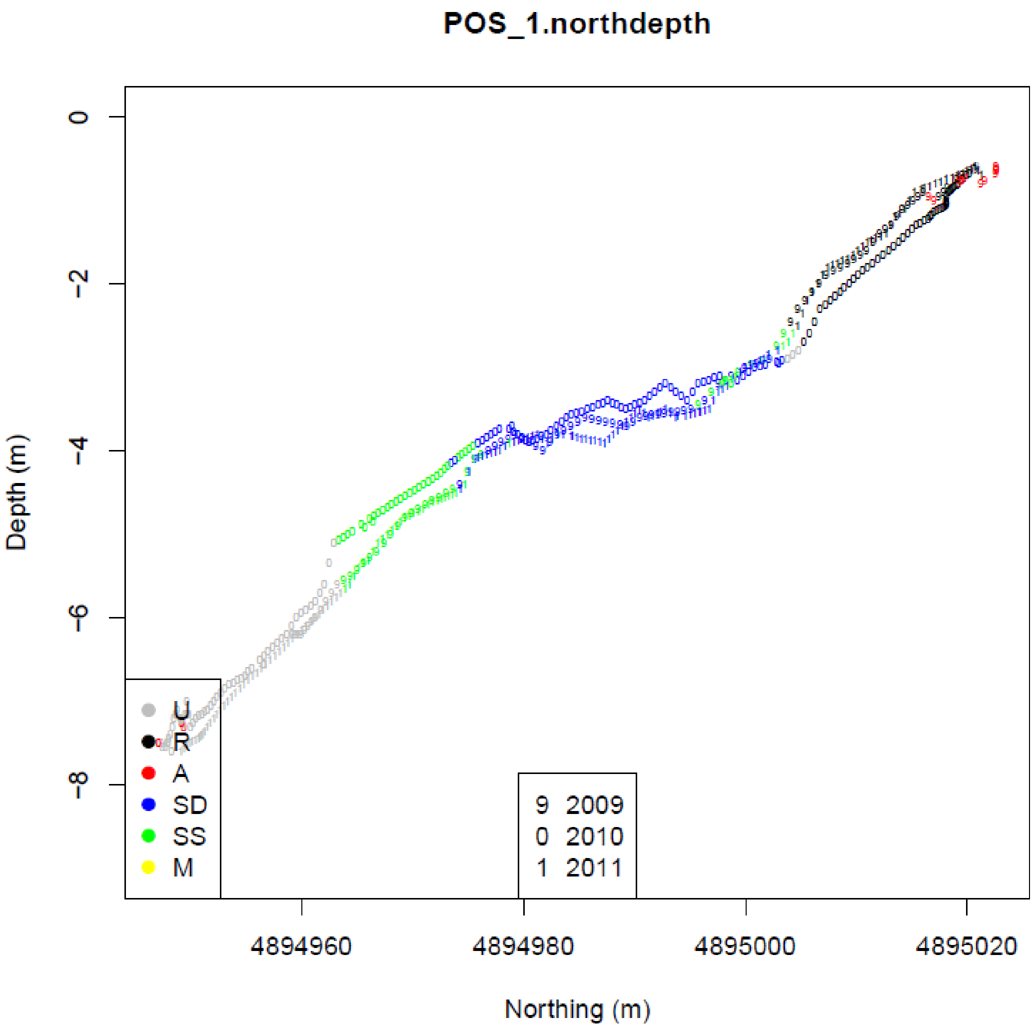

Figure 3.2.2.1. Transect depth profile in three consecutive years. Transect depth profile showing different ground types on the transect, depth and the position. Coloured dots indicate ground type: ● U – Unconsolidated, ● R – Rock, ● A – Algae, ● SD – Dense Seagrass, ● SS – Sparse Seagrass, ● M – Mussels.

3.2.3. Ground cover and seagrass density

There were six different ground cover types, shown in different colors (Figure 3.2.2.1, Table 3.2.3.1.). For each of 20 transects, segments with unconsolidated ground or seagrass were identified. Two same transects in two consecutive years were compared to each other.

Table 3.2.3.1. Ground types and colouring

Ground cover	Color
U (unconsolidated)	⬜
R (rock)	⬛
A (algae)	🟥
SS (sparse seagrass)	🟦
SD (dense seagrass)	🟩
M (mussels)	🟨

There were several possible changes in seagrass cover: the change from seagrass to bare sediment (unconsolidated), from unconsolidated to seagrass, from dense seagrass to sparse seagrass and from sparse seagrass to dense seagrass. The change was displayed as a length of transect where the change occurred and it was measured in meters. Gross and net change from unconsolidated to seagrass and vice versa, and gross and net sediment accumulation were tested for difference on different sides (Posedarje side, natural side). Gross change from unconsolidated ground to seagrass is the change within a transect (in meters) where unconsolidated ground of one year changed to seagrass covered ground in following year.

Gross change from seagrass to unconsolidated ground is a change within transect (in meters) where ground covered in seagrass of one year changed to unconsolidated ground in following year. Gross change from dense seagrass to sparse seagrass is the change within a transect (in meters) where dense seagrass ground of one year changed to sparse seagrass covered ground in following year. Net change in seagrass density is the difference in change from sparse seagrass to dense seagrass.

3.3. Seagrass and sediment sampling

Seagrass and sediment samples were collected for morphological analysis and to determine seagrass biomass and density at 16 sampling sites in Novigrad Sea (8 on north (Posedarje) side which is developed area, and 8 on south (natural) side which is undeveloped) (Figure 3.1.2.). Seagrass and sediment were sampled on all of the 16 sites in each sampling period. The sampling was done in warmer period of the year which is the growing season of seagrass (Borum et al. 2004), in 09/2011, 06/2012, 06/2014 and 10/2014. Eight sites were placed at 3 m depth, and eight at 4.5 meter depth to compare the difference in depth. Sampling sites were located on the line of video-monitored transects. At each location, three samples of seagrass were collected using corer with the sharp edge, 15 cm in diameter (Figure 3.3.1.). Ten shoots from each sample were used for further analysis. If there were less than 10 shoots present in the sample, all of the shoots were used for analysis. Samples were washed and epiphytes removed.

Sediment samples were collected with a syringe corer of 3 cm diameter and dried in the oven at 60°C for 24 h. All seagrass and sediment samples were collected by SCUBA diver. All licences for needed for seagrass sampling were obtained from the Ministry of Environmental Protection.

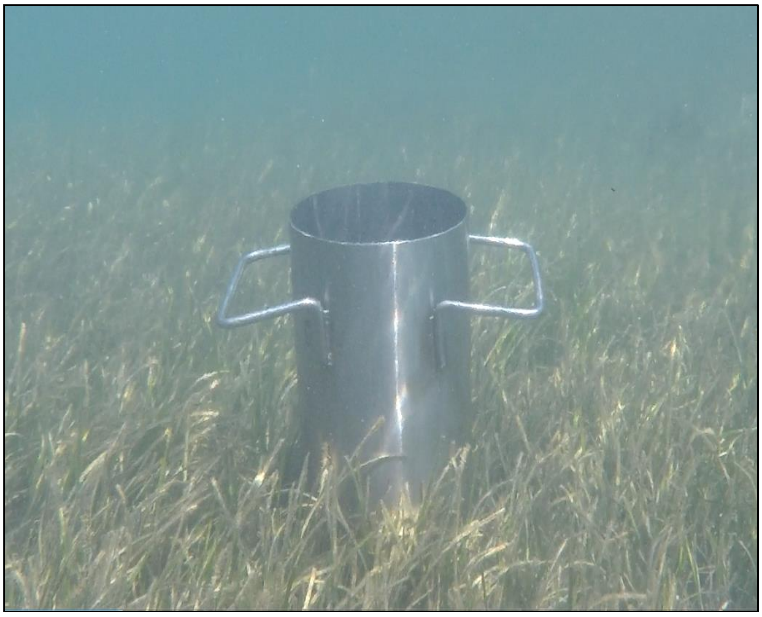

Figure 3.3.1. Seagrass corer used for seagrass sampling (photo: Melita Mokos).

3.4. Seagrass analysis

Seagrass samples collected with corer were used to measure seagrass density, aboveground biomass, belowground biomass, leaf sheath length, leaf length, horizontal internode length and vertical internode length. After sampling, different seagrass species were separated. Aftewards, rhizomes and leaves of each species were separated. Ten shoots of each species from each sample was measured with a ruler and the precision of 0.5 mm. Length of the intacted leaves, internode length and width of 10 internode pieces were measured. After morphological analysis, seagrass samples were dried in the oven at 60°C for 48 h. Dry samples were weighed with balance and the precision of 0.001 g. Dry samples of seagrass were used to measure the aboveground biomass consisted of leaves (AB) and belowground (BG) biomass consisted of rhizomes and roots of each seagrass species in the sample, total biomass (TB) and shoot density (SD). Total abovegroung and belowground biomass was also determined. Total aboveground biomass is the sum of aboveground biomasses of all seagrass species present in the sample. Total belowground biomass is the sum of belowground biomasses of all seagrass species present in the sample.

3.5. Sediment analysis

After collectiog sediment samples, organic matter was determined and granulometric analysis was performed. Granulometric analysis of sediment was done to identify the sediment types across the sampling area. Granulometry was done at the Laboratory of Chemical Oceanography and Sedimentology at the Institute of Oceanography and Fisheries in Split. The grain-size of the sediment samples was determined by sieving (> 0.063 mm) and hydrometering (< 0.063 mm) according to Cassagrande (Strmac, 1952). The hydrometering method is based on the density measurements of suspension in sediment samples, which depends on settling velocity of suspended particles during 48 hours. The obtained density values were used to determine grain-size and to generate of cumulative granulometric curves. Wenthworth (1922) size class was used for particles size. The content of gravel (> 2 mm) and sand (0.063 - 2 mm) particles was determined by sieving. The content of silt (0.004 - 0.063 mm) and clay (< 0.004 mm) particles was determined from the cumulative granulometric curves, constructed toward to the results of grain-size analysis.

The organic matter content was determined by H_2O_2 treatment of the samples at 450°C for 6 hours (Figure 3.5.1.). The loss of weight after this treatment was attributed to the organic matter content (Vdović et al. 1991).

Figure 3.5.1. Laboratory analysis of organic matter content: A) addition of H_2O_2, B) release of CO_2, C) furnace on 450°C, D) weighing of dried samples.

3.6. Sediment accumulation from "sediment traps"

Sediment traps showed on Figure 3.4.1. were used to measure sediment accumulation at 12 sites in Novigrad Sea. Gathered data about sediment accumulation from sediment traps in the studied area served as an indicator for sediment accumulation during the seagrass growing season. Six sediment traps were deployed at 3 m depth and 6 at 4,5 m depth in 09/2010, 06/2011, 06/2014, 10/2014 to determine accumulation rate during growing season of seagrass. Sediment traps were made according to Gacia et al. (1999). Each sediment trap consisted of five 20.5 mL cylindrical glass tubes with an aspect ratio of 5 (16 mm diameter) following recommendations of Hardgrave & Burns (1979) and Blomquist & Hakanson (1989). The tubes were attached to 30 cm long stainless bars by groups of 5, and were separated 4 cm from each other.

Figure 3.4.1. Sediment traps deployed on the sea bottom inside a seagrass meadow (photo: Melita Mokos).

Sediment traps were deployed near the bottom and were taken out from the sea after 15-20 days. During the study period mean wind speed was 1.4 Beaufourt. Dry filters were weighted before the filtering process to know the dry mass of the filter. Accumulated sediment was filtered through the filter and dried for 24 h at 60°C. Filters with sediment were weighted after that. Daily sediment accumulation rate was calculated from the mass of accumulated sediment divided by the number of days the traps were deployed under water.

3.7. Wind data

Data about daily wind speed and wind direction were obtained from the Croatian Meteorological and Hydrological Service for the closest meteorological station, situated in Novigrad, for the period of June 2009 to June 2011. This meteorological station is approximately six kilometers distant from the studied area hence does not completely reflect the true situation on the studied locations. Number of days with eastern and northern winds was counted for the studied period. Number of days with wind speed of 3 and more Beaufort was counted (Table 3.7.1.). Wind speed of 3 Beaufort was chosen as it is the speed where waves start to break.

Table 3.7.1. Summary of wind data (direction and speed). Columns represent number of days per year with wind of different directions and speed of three or more on Beaufort scale.

	Number of days/year	
	2009/2010	2010/2011
Wind direction N, NE	62	90
Beaufort ≥3	35	59
Wind direction S, SE	32	47
Beaufort ≥3	5	11

3.8. Statistical analysis

All the data collected were entered into a database using Microsoft Excel 2007. Statistical programme R (R Core Team 2016) was used for statistical analysis. Descriptive statistical analysis, including means, standard error of the mean and minimum and maximum values were performed. Shapiro-Wilk test was used to test the normality of the seagrass and sediment samples data. The data was not normally distributed so the transformations were done. Following transformations were done in order to get normal distribution: square root, logarithm, squaring. After transformation, data still did not have normal distribution hence non parametric tests were used for further analysis. To test the difference in morphological parameters on different sides and depths a Kruskal Wallis test was used. To test the correlation between sediment accumulation rate and seagrass density, aboveground biomass, leaf length and internode length a Spearman correlation was tested.

Kruskal Wallis test was used for testing the net change in ground cover and seagrass density per meter of transect between years and accumulation pattern (accumulation or erosion). ANOVA was used to test the difference in sediment accumulation between years, side. T-test was used to test the change in ground cover, from unconsolidated to seagrass and seagrass to unconsolidated ground, and change in seagrass density, form sparse to dense and vice versa, between years, side. Kruskal Wallis was used to test the difference in net change between unconsolidated and seagrass ground cover as well as net change between sparse and dense seagrass per meter of transect in relation to net sediment accumulation.

4. RESULTS

4.1. Videographic monitoring

4.1.1. Sediment accumulation and erosion

Gross sediment accumulation at each transect per meter of transect for 2009/2010 and 2010/2011 was calculated and compared on Posedarje and natural side, and years (Table 4.1.1.1.). Gross sediment accumulation per transect meter which occurred from 2009 to 2010 ranged from 0.09 to 206.43 cm^2 m^{-1} $year^{-1}$ with the mean of 26.79 ± SEM 11.12 cm^2 m^{-1} $year^{-1}$, whereas from 2010 to 2011 it ranged from 52.20 to 35250.00 cm^2 m^{-1} $year^{-1}$ with the mean of 16.56 ± 5.15 cm^2 m^{-1} $year^{-1}$. No significant difference was found when year ($p = 0.239$), and side ($p = 0.443$) were compared. Total gross sediment accumulation in all three years per meter of transect showed no difference when sides ($p = 0.389$) were compared.

Table 4.1.1.1. Results of ANOVA analysis for difference in gross sediment accumulation per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	860	860	0.602	0.443
year	1	2053	2053	1.436	0.239
Residuals	36	51448	1429		

Gross sediment erosion per meter of transect was calculated and compared for 2009/2010 and 2010/2011 on different sides, and years (Table 4.1.1.2.). Gross sediment erosion per transect which occurred from 2009 to 2010 ranged from 0.90 to 55.25 cm^2 m^{-1} $year^{-1}$ with the mean of 9.79 ± 3.64 cm^2 m^{-1} $year^{-1}$ whereas from 2010 to 2011 it ranged from 51.84 to 292.51 cm^2 m^{-1} $year^{-1}$ with the mean of 29.11 ± 15.27 cm^2 m^{-1} $year^{-1}$. The analysis did not show significant difference between years ($p = 0.143$), and sides ($p = 0.974$). Total gross sediment erosion is the sum of sediment erosion of all three years (2009, 2010, 2011). No difference was found in total gross sediment erosion in all three years per meter of transect on different sides ($p = 0.672$).

Table 4.1.1.2. Results of ANOVA analysis for difference in gross sediment erosion per meter of transect between different sides, and years

	df	SS	MS	F	p
side	1	3	2.6	0.001	0.974
year	1	5551	5551	2.242	0.143
Residuals	36	89143	2476		

Mean net sediment accumulation from 2009 to 2010 was 16.99 $cm^2\ m^{-1}\ year^{-1}$ (SEM = 12.46 $cm^2\ m^{-1}\ year^{-1}$) and -0.77 $cm^2\ m^{-1}\ year^{-1}$ from 2010 to 2011. Net sediment accumulation of each year was compared and it was not significantly different on different sides ($p = 0.646$), however it was higher on Posedarje side compared to natural side in 2010/2011 (Table 4.1.1.3.). The effect of a year on net sediment accumulation was heading near significance ($p = 0.082$) (Table 4.1.1.4.). Positive values represent sediment accumulation and negative values represent sediment erosion.

Table 4.1.1.3. Mean values of net sediment accumulation (Netaccum), net change from unconsolidated to seagrass ground (Netusg) and net change from sparse to dense seagrass (Netsssd) on all monitored transects in two time intervals 2009/2010 and 2010/2011 on both sides (total), Posedarje side and natural side.

	2009/2010			2010/2011		
	TOTAL	POS	NAT	TOTAL	POS	NAT
Netaccum ($cm^2\ m^{-1}\ year^{-1}$)	16.99	21.33	15.25	-0.77	13.68	-24.56
Netusg (m_{sg}/m_{tr})	0.03	0.02	0.04	-0.001	-0.02	0.02
Netsssd (m_{sg}/m_{tr})	-0.01	0.02	0.02	0.02	-0.02	0.06

Table 4.1.1.4. Results of ANOVA analysis for difference in net sediment accumulation per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	3	2.6	0.214	0.646
year	1	5551	5551	3.210	0.082
Residuals	36	89143	2476		

Total net sediment accumulation is the sum of sediment accumulation on all transects of all three years (2009, 2010, 2011). The difference in total net sediment accumulation of all three years per meter of transect on different sides (*p* = 0.557) was also not significant.

4.1.2. Seagrass cover change

Gross change in seagrass cover from unconsolidated ground to seagrass per meter of transect from 2009 to 2010 was mean 0.05 ± 0.007 m_{sg}/m_{tr} and ranged from 0.02 to 0.11 m_{sg}/m_{tr}, whereas from 2010 to 2011 it ranged from 0.01 to 0.21 m_{sg}/m_{tr}. It showed no significant difference when compared to different sides (*p* = 0.830), and it also did not show significant difference when 2009/2010 was compared to 2010/2011 (*p* = 0.211).

Table 4.1.2.1. Results of ANOVA analysis for difference in ground type from unconsolidated ground to seagrass cover per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	0.000037	0.000037	0.047	0.830
year	1	0.0013	0.0013	1.621	0.211
Residuals	36	0.028	0.00078		

Gross change from seagrass to unconsolidated was found to be significantly higher on Posedarje side (*p* = 0.024) and in 2010/2011 (*p* = 0.034).

Table 4.1.2.2. Results of ANOVA analysis for difference in ground type from seagrass cover to unconsolidated ground per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	0.0045	0.0045	5.519	0.024
year	1	0.0039	0.0039	4.835	0.034
Residuals	36	0.029	0.00081		

Gross change from sparse seagrass to dense seagrass is the change within transect (in meters) where sparse seagrass ground of one year changed to dense seagrass covered ground in following year.

Mean gross change of seagrass density from sparse seagrass cover to dense seagrass cover per meter of transect was 0.04 m_{sg}/m_{tr} in 2009/2010 and ranged from 0.01 to 0.16 m_{sg}/m_{tr} (± 0.009), whereas in 2010/2011 the mean was 0.06 m_{sg}/m_{tr} ± 0.02 and ranged from 0.01 to 0.27. It was not significant on different sides (p = 0.455), and years (p = 0.624).

Table 4.1.2.3. Results of ANOVA analysis for difference in seagrass density change from sparse seagrass to dense seagrass per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	0.0014	0.0014	0.570	0.455
year	1	0.00060	0.00060	0.244	0.624
Residuals	36	0.089	0.0025		

The opposite change, from dense to sparse seagrass per meter of transect in 2009/2010 was mean 0.05 m_{sg}/m_{tr} ± 0.02 and ranged from 0.01 to 0.31 m_{sg}/m_{tr}, whereas in 2010/2011 it was mean 0.04 m_{sg}/m_{tr} ± 0.01 and ranged from 0.02 to 0.16 m_{sg}/m_{tr}. Change from dense seagrass to sparse was also not found to be significantly different in different years (p = 0.215), though the difference in sides was significant (p = 0.027) with higher change from dense to sparse seagrass on Posedarje side with loss of 0.005 m_{dsg}/m_{tr} in the whole period from 2009 to 2011.

Table 4.1.2.4. Results of ANOVA analysis for difference in seagrass density change from dense seagrass to sparse seagrass per meter of transect between different sides, and years.

	df	SS	MS	F	p
side	1	0.0069	0.0069	5.346	0.027
year	1	0.0021	0.0020	1.592	0.215
Residuals	36	0.046	0.0013		

Total net change from unconsolidated to seagrass over the three years per meter of transect was significantly higher on natural side with $p = 0.016$. Comparison of net change from unconsolidated to seagrass ground between 2009/2010 and 2010/2011 showed that 2009/2010 was a year of seagrass gain with higher change from unconsolidated to seagrass, while 2010/2011 was a year of seagrass loss with higher change from seagrass to unconsolidated ground (Table 4.1.1.3.) and this difference was highly significant ($p = 0.007$). Additionally, the net change from unconsolidated to seagrass ground in all three years was not significantly different due to sediment accumulation ($p = 0.349$).

Mean net change in seagrass density from 2009 to 2010 was -0.01 ± 0.02 m_{sg}/m_{tr} and ranged from -0.27 to 0.15 with negative values indicating loss of dense seagrass and positive values gain of dense seagrass. In the period from 2010 to 2011, mean was 0.02 ± 0.02 and ranged from -0.14 to 0.22. Total net change in seagrass density of all three years per meter of transect was significantly different ($p = 0.035$) depending on whether accumulation or erosion occurred. The results indicate more transect meters with sparse seagrass in the conditions of sediment accumulation whereas the area with erosion conditions had more of dense seagrass.

4.2. Seagrass morphology and biomass

Seagrass samples were collected from a mixed seagrass bed which consists of three seagrass species: *Zostera noltei*, *Zostera marina* and *Cymodocea nodosa* (Figure 3.1.2.). Total seagrass density ranged between 56 and 5198 shoots/m^2. Mean total seagrass density was 1405 ± SEM 61.65 shoots/m^2. Significantly higher density was recorded on natural side with average density 1627 N_{shoots}/m^2 while on Posedarje side mean was 1171 shoots/m^2. Total seagrass density was also significantly higher on three meter depth with average of 1793 shoots/m^2 while the average on 4.5 meter depth was 1013 shoots/m^2.

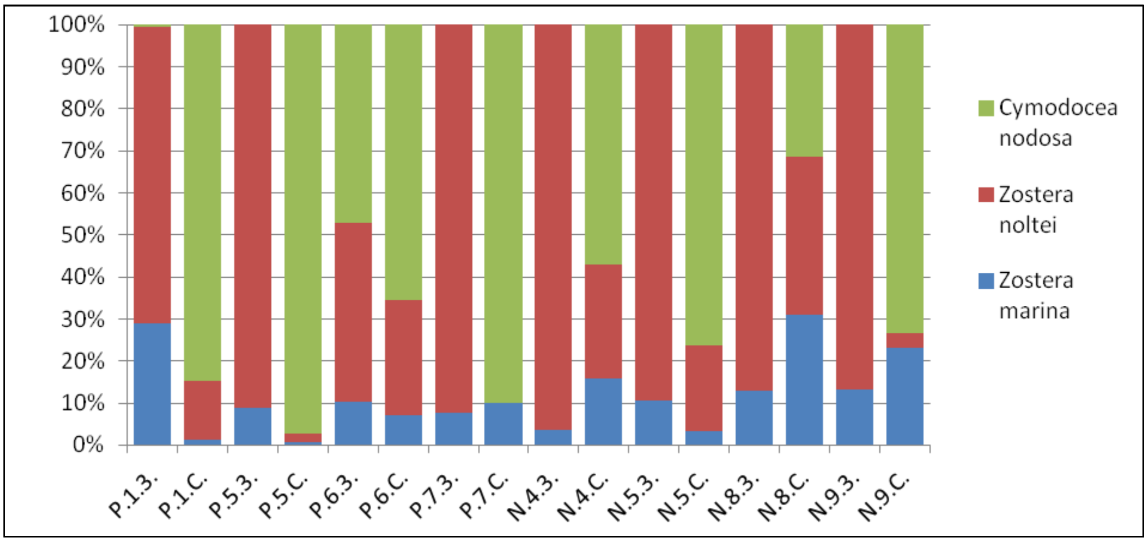

Figure 4.2.1. Total seagrass density (%) among sampling sites. On the x-axis, in the name of sampling site, “P” indicates Posedarje side, “N” indicates natural side, number “3” indicates 3 meter depth and “C” indicates 4.5 meter depth. Position of sampling sites are shown in Figure 3.1.2.

Total aboveground biomass ranged between 1.9 and 135.7 gdw/m^2. Mean total aboveground biomass was 44.0 ± 2.02 gdw/m^2. Significantly higher total aboveground biomass was recorded on natural side with average aboveground biomass 49.6 gdw/m^2 while on Posedarje side mean was 38.1 gdw/m^2. No significant difference was found on different depths ($p = 0.340$).

Total belowground biomass ranged between 4.1 and 351.1 gdw/m^2. Mean total belowground biomass was 126.4 ± 5.50 g/m^2. No significant difference was found on different sides ($p = 0.244$) while it was significantly higher on 4.5 meter depth ($p < 0.001$) with mean 156.4 gdw/m^2 compared to 95.9 on 3 meter depth.

4.2.1. Biomass, density and morphological analysis of *Zostera noltei*

4.2.1.1. Biomass

Aboveground biomass of *Z. noltei* ranged from 0.1 to 93.7 gdw/m^2. Mean value of aboveground biomass was 26.5 ± 1.98 gdw/m^2. *Zostera noltei* aboveground biomass was significantly higher on natural side ($p = 0.023$) and on 3 meter depth ($p < 0.001$). No correlation between aboveground biomass and sediment accumulation rate was found ($p = 0.600$).

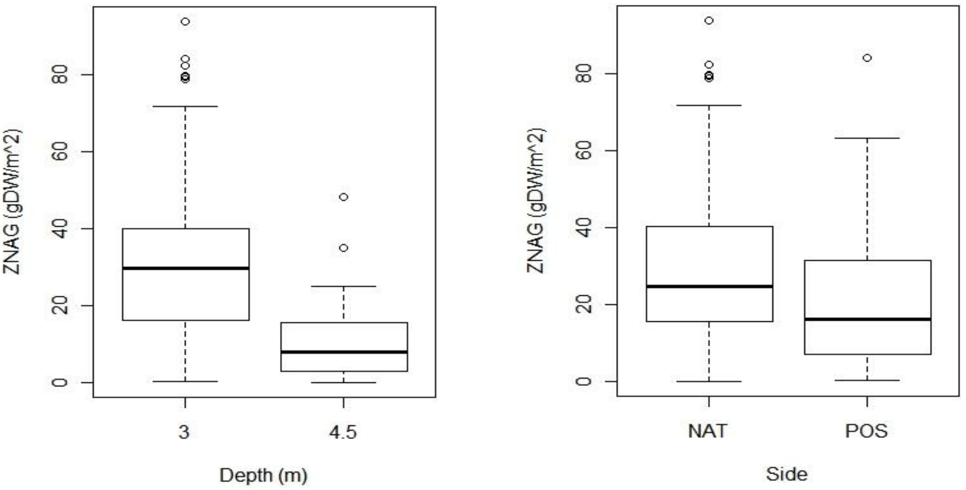

Figure 4.2.1.1.1. Dry aboveground biomass of *Zostera noltei* at (a) different depth (3 and 4,5 meter) and (b) sides (POS-Posedarje and NAT-natural). Boxes encompass 50% of the values, the bold line represents the median value, the dots represent the outliers and the bars extend to 1.5 times the interquartile range.

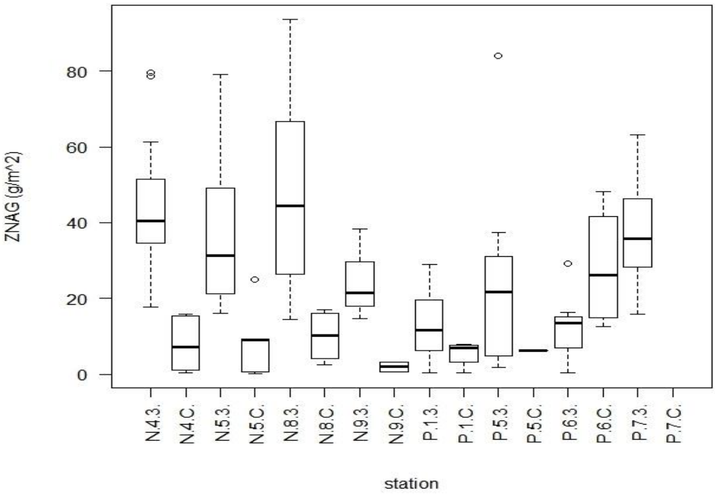

Figure 4.2.1.1.2. *Zostera noltei* dry aboveground biomass by sampling sites.

Belowground biomass of *Z. noltei* ranged from 0.3 g/m^2 to 151.6 gdw/m^2. Mean value of belowground biomass was 48.1 ± 3.31 gdw/m^2. There was a significant difference in *Z. noltei* belowground biomass on different sides ($p = 0.001$) and different depths ($p < 0.001$) with higher values on natural side and 3 meter depth. No correlation between belowground biomass and sediment accumulation rate was found ($p = 0.529$).

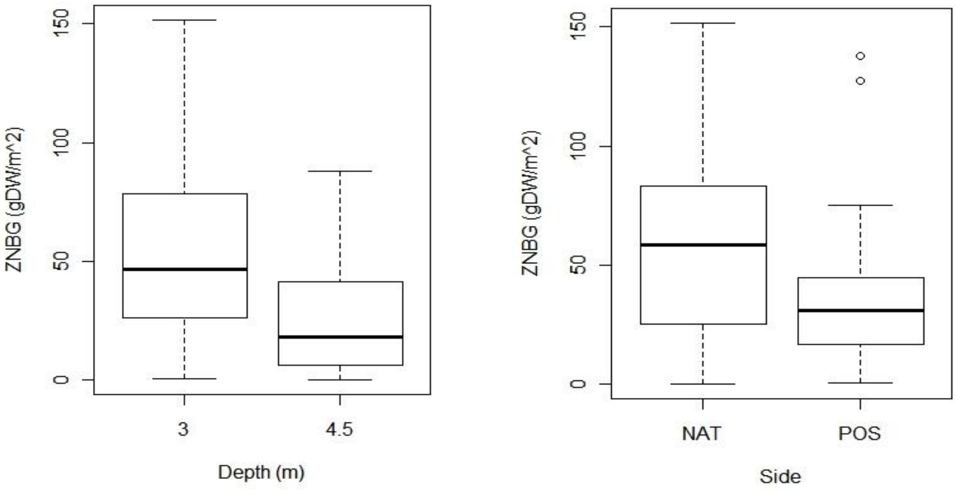

Figure 4.2.1.1.3. Dry belowground biomass of *Zostera noltei* at different depth (a) and sides (b).

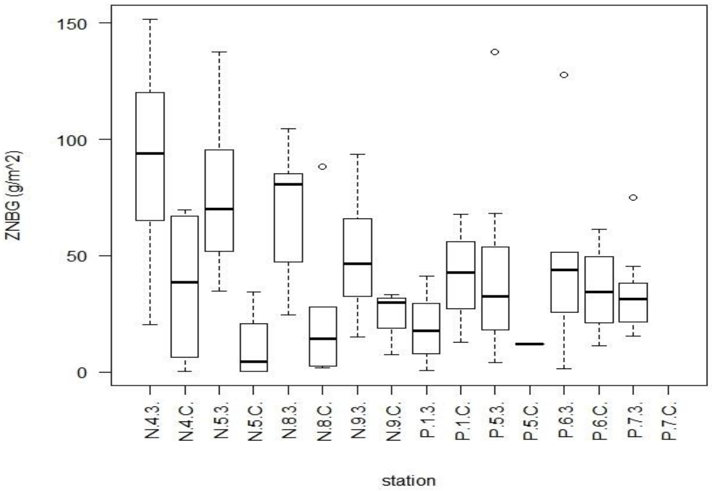

Figure 4.2.1.1.4. *Zostera noltei* dry belowground biomass by sampling sites.

4.2.1.2. Shoot density, leaf length, leaf sheath length and internode length and width

Shoot density of *Zostera noltei* ranged from 57 to 5028 shoots/m^2. Mean value of shoot density was 1382 ± 85.09 shoots/m^2. *Zostera noltei* density was significantly higher on natural side (p = 0.002) and at 3 meter depth ($p < 0.001$). No correlation between density and sediment accumulation rate was found (p = 0.356).

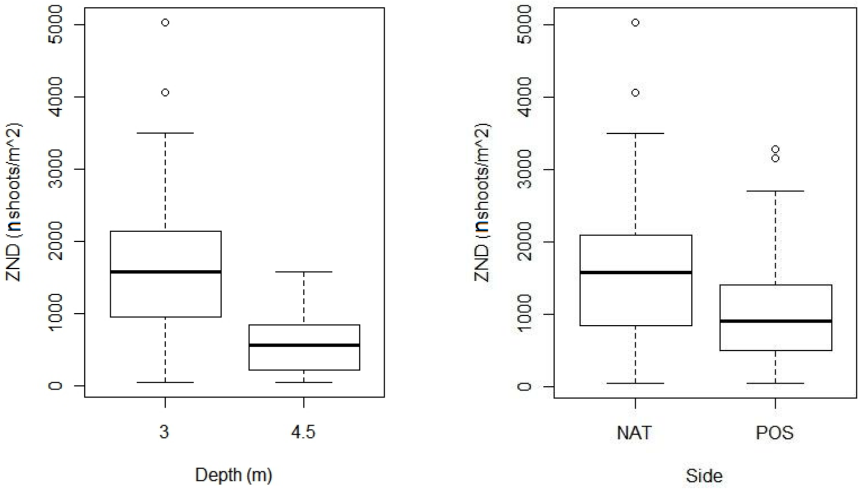

Figure 4.2.1.2.1. Shoot density of *Zostera noltei* (ZND) at different depth (a) and sides (b).

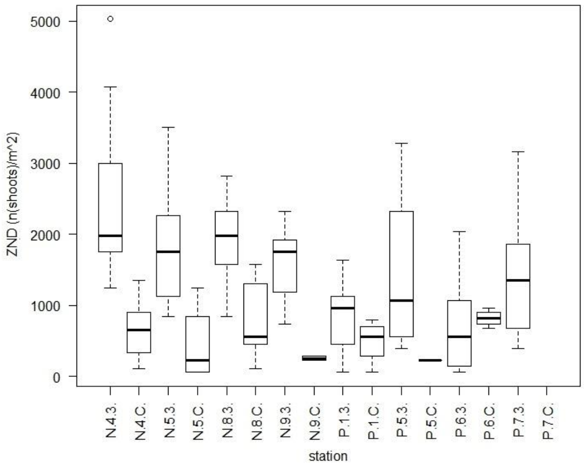

Figure 4.2.1.2.2. *Zostera noltei* shoot density by sampling sites.

Leaf length ranged from 2.4 cm to 62 cm. Mean value of leaf length was 21.1 ± 0.35 cm. There was no significant difference in *Z. noltei* leaf length on different sides ($p = 0.494$) and different depths ($p = 0.494$). Correlation between leaf length and sediment accumulation rate was not found ($p = 0.972$).

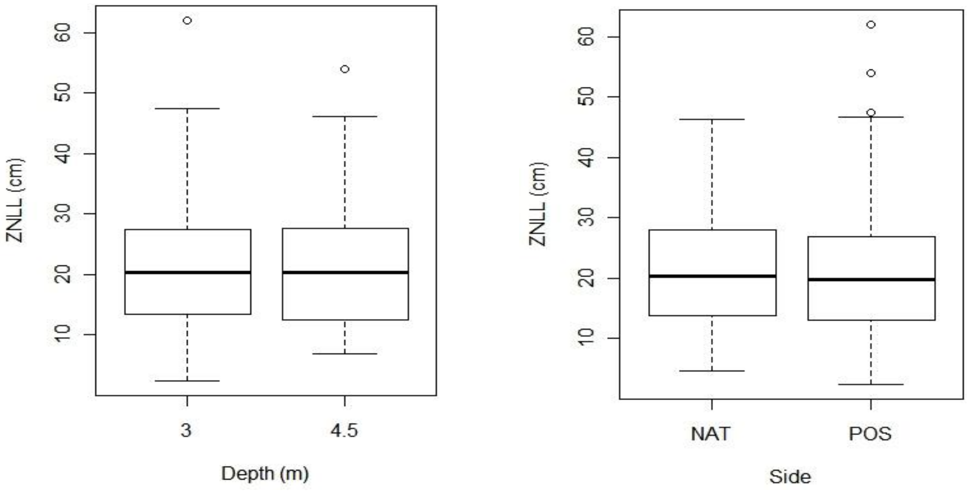

Figure 4.2.1.2.3. Leaf length of *Zostera noltei* (ZNLL) at different depth (a) and sides (b).

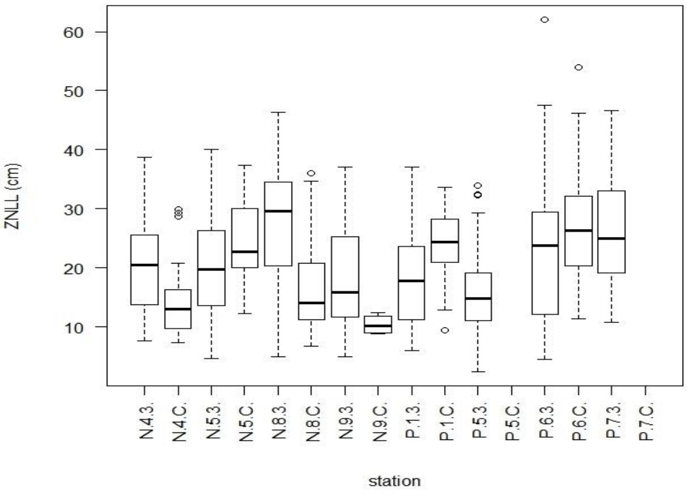

Figure 4.2.1.2.4. *Zostera noltei* leaf length by sampling sites.

Leaf sheath length ranged from 0.1 cm to 11.4 cm. Mean value of leaf sheath length was 3.4 ± 0.1 cm. There was no difference ($p = 0.864$) in *Z. noltei* leaf sheath length on different sides and different depths ($p = 0.170$). No correlation between leaf sheath length and sediment accumulation rate was found ($p = 0.438$).

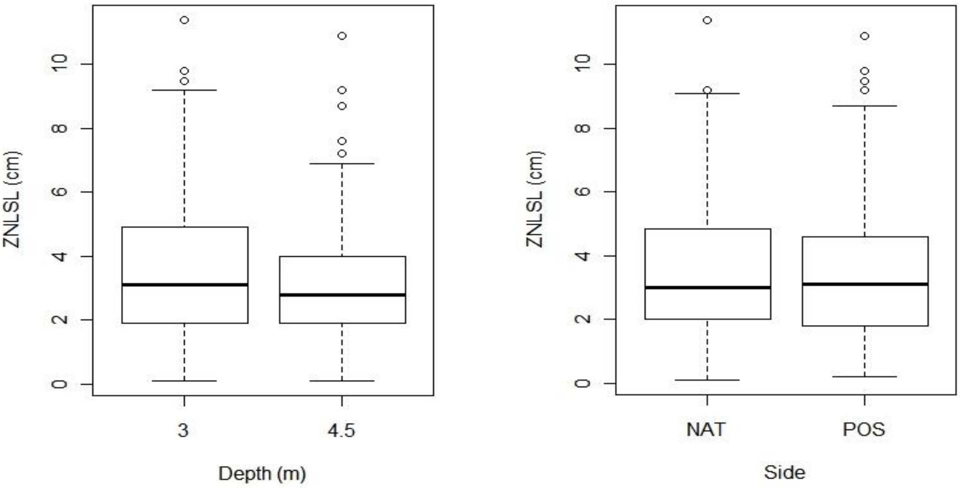

Figure 4.2.1.2.5. Leaf sheath length of *Zostera noltei* (ZNLSL) at different depth (a) and sides (b).

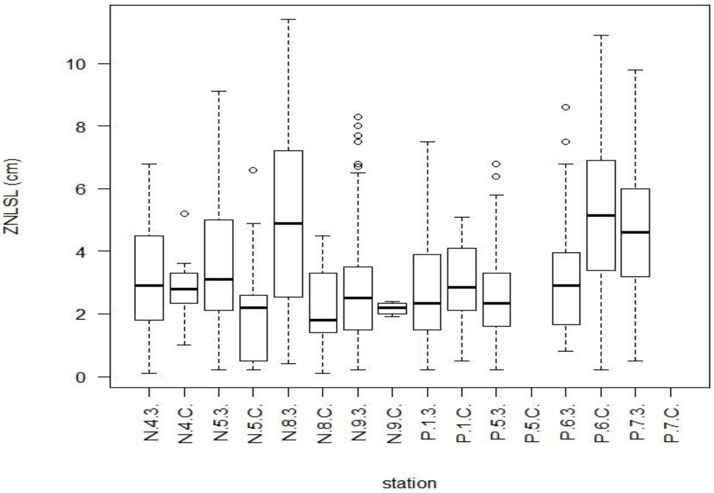

Figure 4.2.1.2.6. *Zostera noltei* leaf sheath length by sampling sites.

Horizontal internode length ranged from 0.2 cm to 3.9 cm with the mean length of 1.3 ± 0.02 cm. Significant difference of *Z. noltei* horizontal internode length at different sides was not found ($p = 0.195$), while there was a significant depth difference ($p < 0.001$) with longer internodes on 3 meter depth. No correlation between horizontal internode length and sediment accumulation rate was found ($p = 0.539$). Vertical internodes (Figure 4.2.1.2.7.) of *Zostera noltei* were recorded.

Figure 4.2.1.2.7. Vertical rhizome with vertical internodes in *Zostera noltei*.

Vertical internode length ranged from 0.1 cm to 1.0 cm with mean value 0.3 ± 0.01. Vertical internode length (ZNVIL) was significantly shorter than horizontal internode length (ZNHIL) ($p < 0.001$). Mean ZNVIL was 0.3 cm (n=331), while mean ZNHIL was 1.3 cm. *Zostera noltei* vertical internodes were significantly longer on natural side ($p = 0.038$) and at 3 meter depth ($p < 0.001$). Significant correlation between vertical internode length and sediment accumulation rate was moderate ($p = 0.026$, rho = 0.46).

Table 4.2.1.2.1. Morphological characteristics of *Zostera noltei*. Mean values, standard error of the mean and number of samples are presented (ZNAG – *Z. noltei* aboveground biomass, ZNBG – *Z. noltei* belowground biomass, ZND – *Z. noltei* shoot density, ZNLL - *Z. noltei* leaf length, ZNLSL - *Z. noltei* leaf sheath length, ZNHIL - *Z. noltei* horizontal intenode length, ZNVIL - *Z. noltei* vertical internode length).

	Natural			Posedarje		
	mean	SEM	n	mean	SEM	n
ZNAG (gdw/m^2)	30.5	2.8	67	21.2	2.4	53
ZNBG (gdw/m^2)	57.7	4.8	67	35.3	3.7	53
ZND (shoots/m^2)	1605	119	67	1096	110	53
ZNLL (cm)	21.1	0.4	452	21.0	0.6	289
ZNLSL (cm)	3.4	0.1	452	3.4	0.1	289
ZNHIL (cm)	1.2	0.03	632	1.1	0.03	450
ZNVIL (cm)	0.3	0.02	168	0.3	0.01	163

4.2.2. Biomass, density and morphological analysis of *Zostera marina*

4.2.2.1. Biomass

Aboveground biomass of *Zostera marina* ranged from 0.3 to 77.9 gdw/m^2. Mean value of aboveground biomass was 14.8 ± 1.42 gdw/m^2. There was a significant difference ($p = 0.012$) in aboveground biomass on different sides with higher values on natural side. No significant difference on different depths ($p = 0.759$) was found. Weak correlation between aboveground biomass and sediment accumulation rate was found ($p = 0.037$, rho = 0.23).

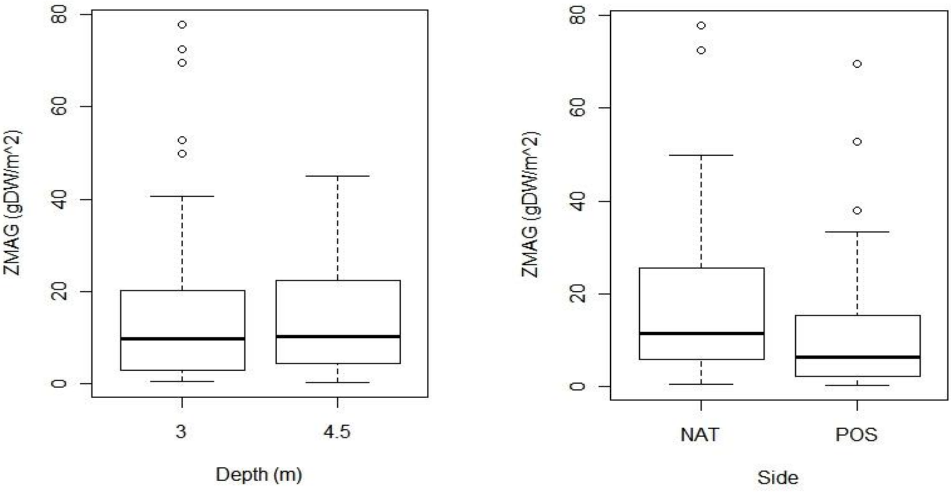

Figure 4.2.2.1.1. Dry aboveground biomass of *Zostera marina* (ZMAG) at different depth (a) and sides (b).

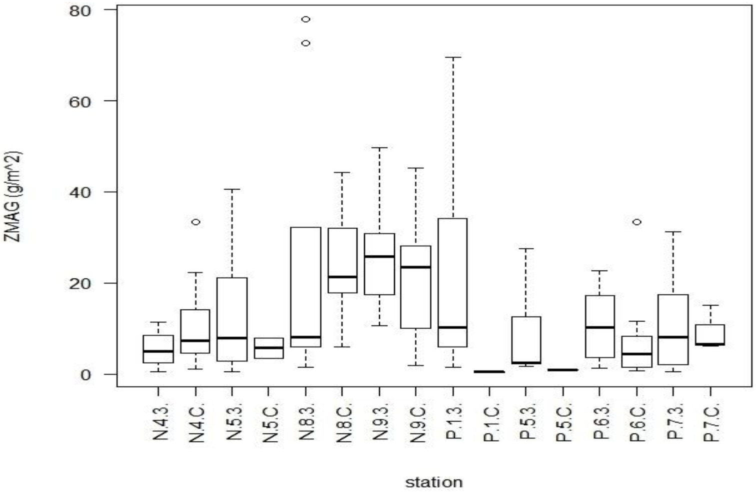

Figure 4.2.2.1.2. *Zostera marina* dry aboveground biomass by sampling sites.

Belowground biomass of *Z. marina* ranged from 1.0 gdw/m^2 to 155.4 gdw/m^2. Mean value of belowground biomass was 40.9 ± 3.26 gdw/m^2. Species *Z. marina* belowground biomass was significantly higher on natural side ($p = 0.027$), but no significant difference on different depths ($p = 0.312$) was found. No correlation between belowground biomass and sediment accumulation rate was found ($p = 0.452$).

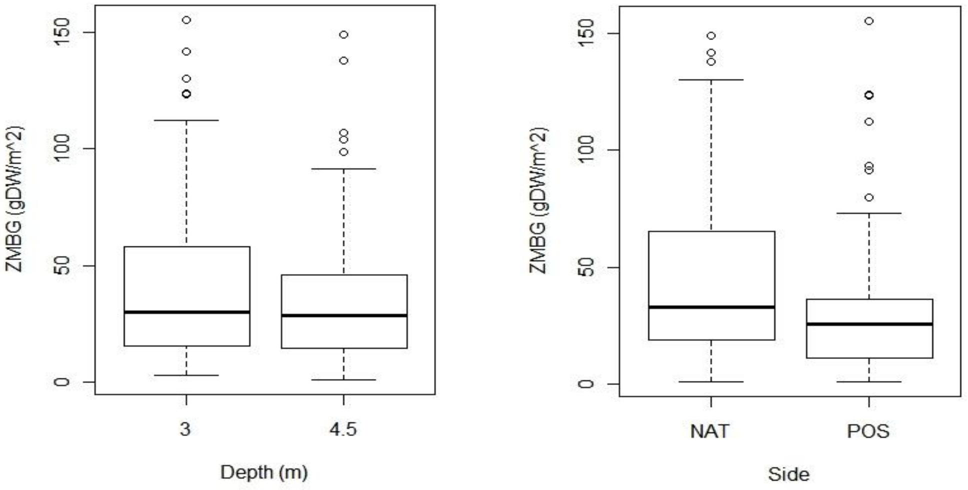

Figure 4.2.2.1.3. Dry belowground biomass of *Zostera marina* (ZMBG) at different depth (a) and sides (b).

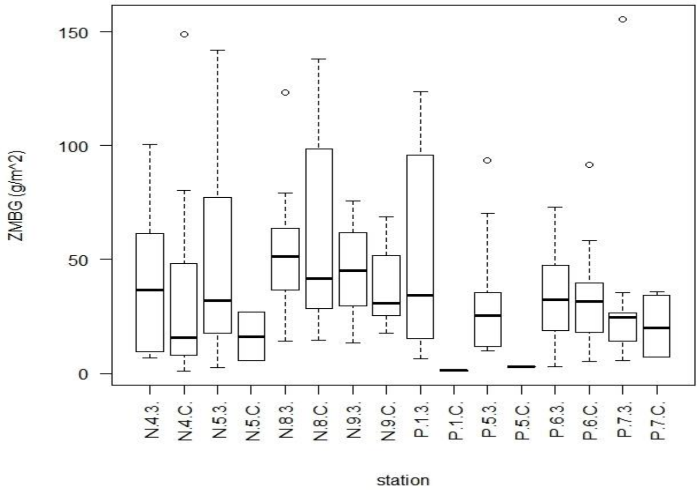

Figure 4.2.2.1.4. *Zostera marina* dry belowground biomass by sampling sites.

4.2.2.2. Shoot density, leaf length, leaf sheath length and internode length and width

Shoot density ranged from 57 to 1130 shoots/m^2. Mean value of shoot density was 248 ± 20.29 shoots/m^2. *Zostera marina* density was significantly higher on natural side ($p < 0.001$) but no significant difference on different depths was found ($p = 0.372$). Weak positive correlation between density and sediment accumulation rate was found ($p = 0.004$, rho = 0.31).

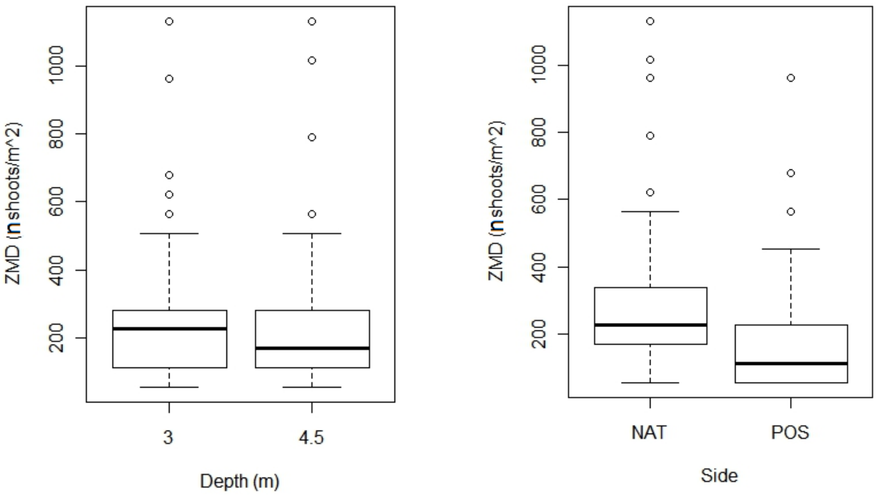

Figure 4.2.2.2.1. Shoot density of *Zostera marina* (ZMD) at different depth (a) and sides (b).

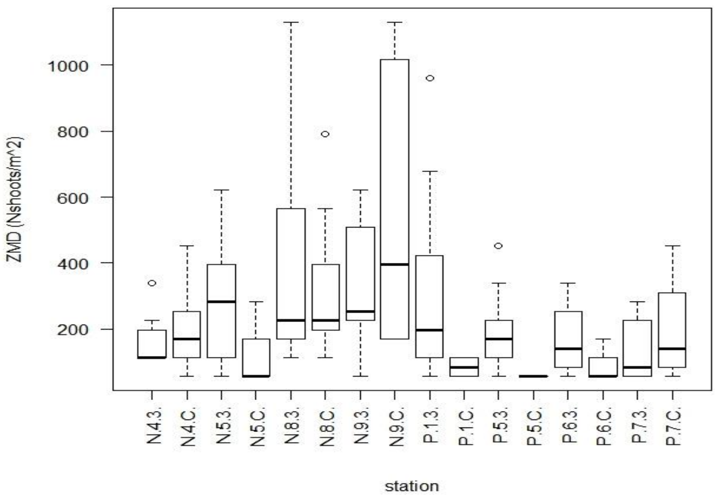

Figure 4.2.2.2.2. *Zostera marina* shoot density by sampling sites.

Leaf length ranged from 4.8 cm to 41.2 cm. Mean value of leaf length was 18.1 ± 0.52 cm. *Zostera marina* leaves were significantly longer on Posedarje side ($p < 0.001$) but no difference on different depths was found ($p = 0.407$). Correlation between leaf length and sediment accumulation rate was not found ($p = 0.832$, rho = 0.03).

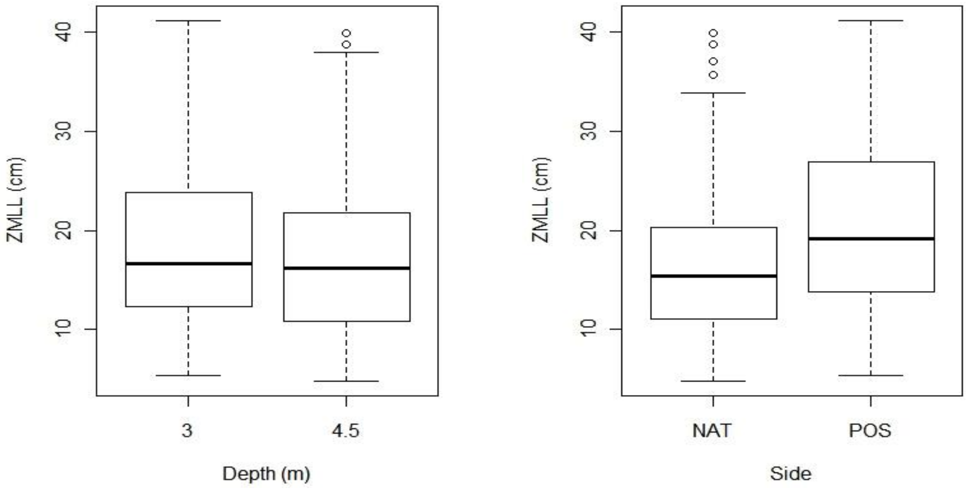

Figure 4.2.2.2.3. Leaf length of *Zostera marina* (ZMLL) at different depth (a) and sides (b).

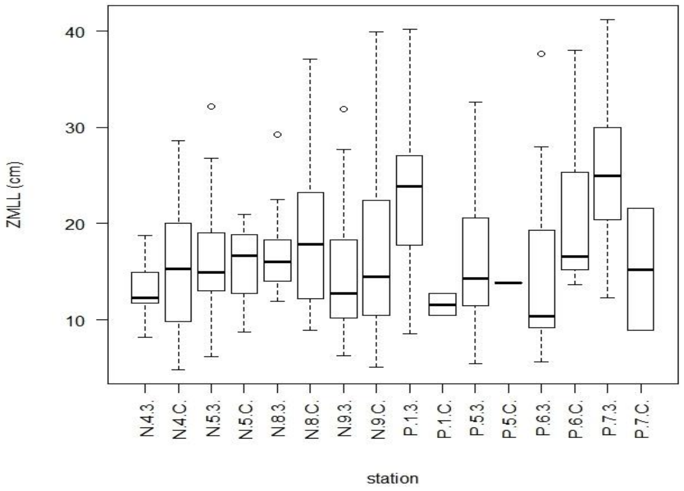

Figure 4.2.2.2.4. *Zostera marina* leaf length by sampling sites.

Leaf sheath length ranged from 0.3 to 12.2. Mean value of leaf sheath length was 3.7 ± 0.12 cm. Leaf sheath in *Z. marina* was significantly longer on Posedarje side ($p = 0.027$) while there was no difference on different depths ($p = 0.300$). There was no correlation between leaf sheath length and sediment accumulation rate ($p = 0.248$).

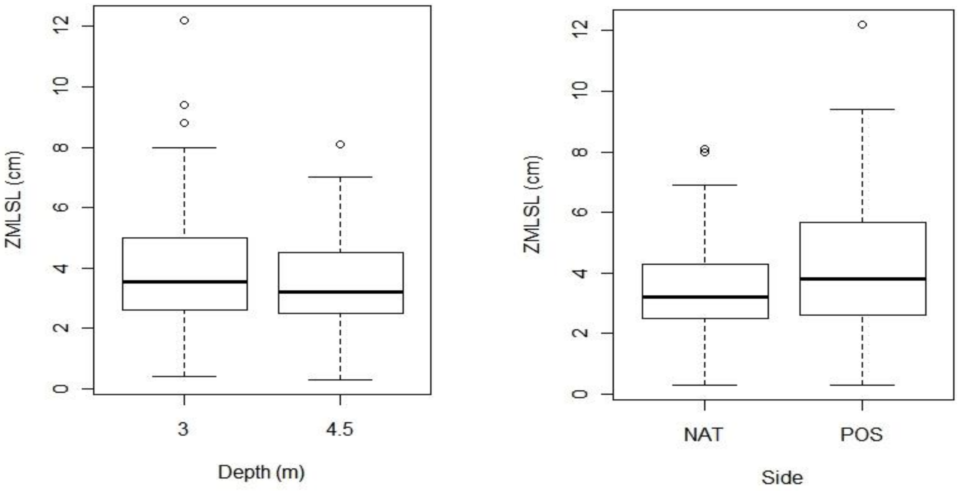

Figure 4.2.2.2.5. Leaf sheath length of *Zostera marina* (ZMLSL) at different depth (a) and sides (b).

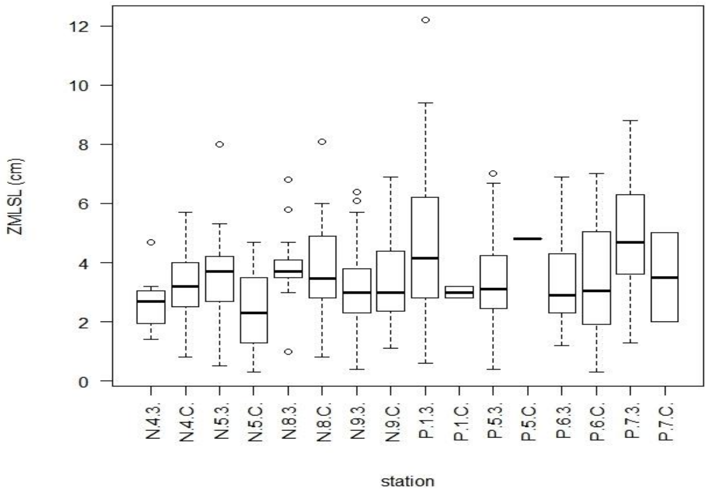

Figure 4.2.2.2.6. *Zostera marina* leaf sheath length by sampling sites.

Horizontal internode length ranged from 0.2 cm to 2.7 cm with the mean length of 1.0 ± 0.01. Horizontal internodes of species *Z. marina* were significantly longer on Posedarje side (p = 0.012) and at 3 meter depth ($p < 0.001$). No correlation was found between horizontal internode length and sediment accumulation (p = 0.343).

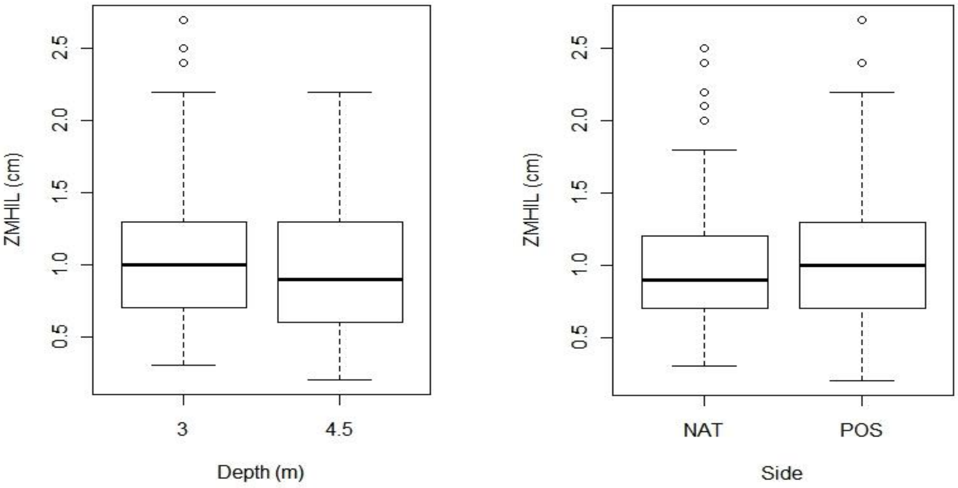

Figure 4.2.2.2.7. Horizontal internode length of *Zostera marina* (ZMHIL) at different depth (a) and side (b).

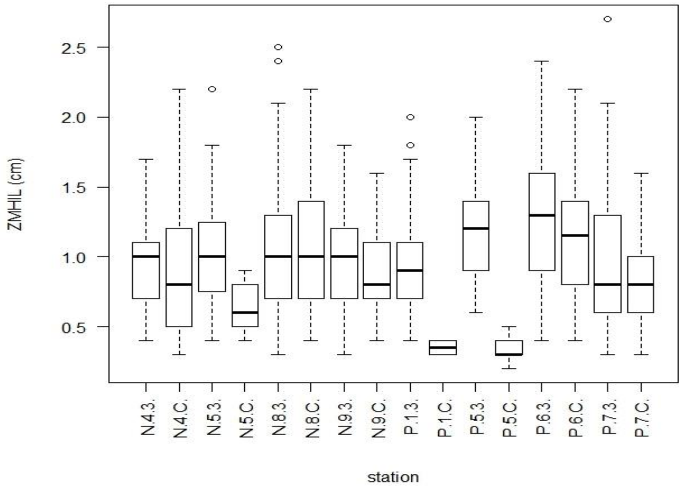

Figure 4.3.2.2.8. *Zostera marina* horizontal internode length by sampling sites.

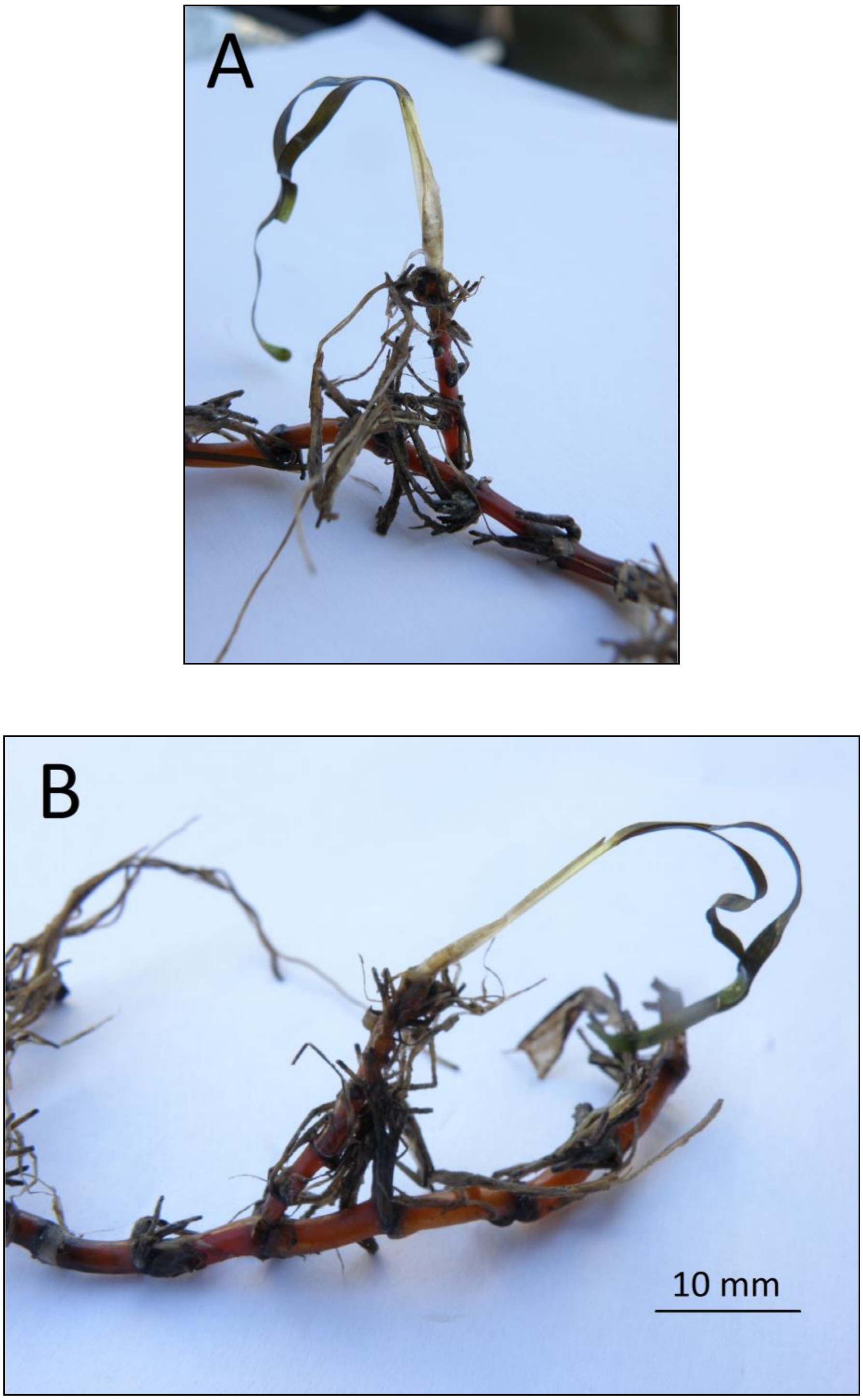

Figure 4.2.2.2.9. Vertical rhizome with vertical internodes in *Zostera marina* (A and B).

Vertical rhizome of *Z. marina* (Figure 4.2.2.2.9.) was recorded for the first time according to existing literature. Vertical rhizomes in *Z. marina* are defined as a stem oriented vertically, buried in sediment, originating from a horizontal rhizome, bearing roots at internodes. Vertical internode length (ZMVIL) ranged from 0.1 cm to 1.2 cm with mean value 0.4 ± 0.01 (n = 237). Vertical internode length differed significantly from horizontal internode length (ZMHIL) (p <

0.001). Mean vertical internode length was 0.4 cm, while the mean horizontal internode length was 1.0 cm. Number of vertical rhizomes in seagrass sample varied among stations. Number of vertical rhizomes present in seagrass sample varied from 1 to 5. Mean number of vertical rhizomes in collected samples was 1.9 ± 0.2. No significant difference was found in vertical internode length on different sides ($p = 0.085$) and different depths ($p = 0.944$). Correlation between *Z. marina* vertical internode length and sediment accumulation rate was not found ($p = 0.194$).

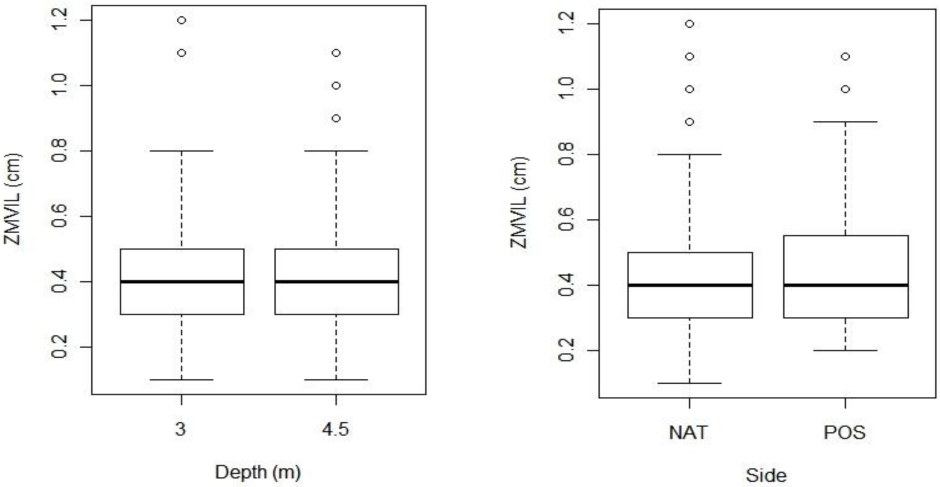

Figure 4.2.2.2.10. Vetical internode length of *Zostera marina* (ZMVIL) at different depth (a) and side (b).

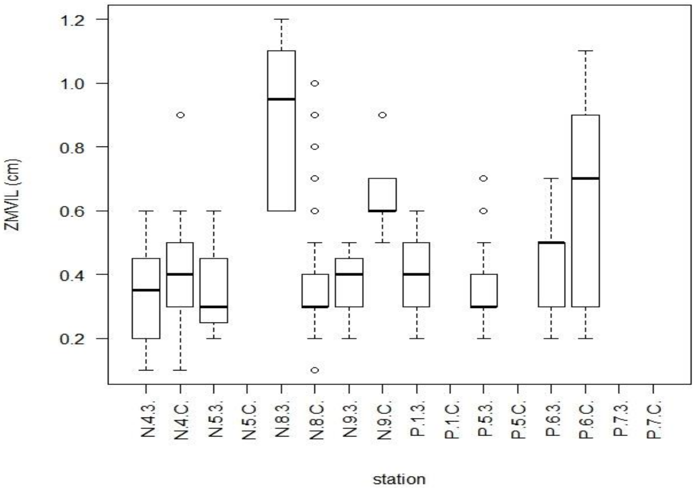

Figure 4.2.2.2.11. *Zostera marina* vertical internode length by sampling sites.

Table 4.2.1.2.1. Morphological characteristics of *Zostera marina*. Mean values, standard error of the mean and number of samples are presented (ZMAG – *Z. marina* aboveground biomass, ZMBG – *Z. marina* belowground biomass, ZMD – *Z. marina* shoot density, ZMLL - *Z. marina* leaf length, ZMLSL - *Z. marina* leaf sheath length, ZMHIL - *Z. marina* horizontal intenode length, ZMVIL - *Z. marina* vertical internode length).

	Natural			Posedarje		
	mean	SEM	n	mean	SEM	n
ZMAG (gdw/m^2)	17.5	2.0	66	11.7	1.9	54
ZMBG (gdw/m^2)	46.6	4.6	66	34.2	4.6	54
ZMD (shoots/m^2)	304.7	31.1	66	181.4	20.7	54
ZMLL (cm)	16.6	0.6	156	20.8	1.0	88
ZMLSL (cm)	3.4	0.1	156	4.1	0.2	88
ZMHIL (cm)	1.0	0.01	606	1.0	0.02	493
ZMVIL (cm)	0.4	0.01	169	0.4	0.02	68

4.2.3. Biomass, density and morphological analysis of *Cymodocea nodosa*

4.2.3.1. Biomass

Aboveground biomass of *Cymodocea nodosa* (CNAG) ranged from 0.1 to 135.1 gdw/m^2. Mean value of aboveground biomass was 35.5 ± 2.86 gdw/m^2. There was a no significant difference of *C. nodosa* aboveground biomass on different sides (p = 0.968) or at different depths (p = 0.438). No correlation between aboveground biomass and sediment accumulation rate was found (p = 0.797).

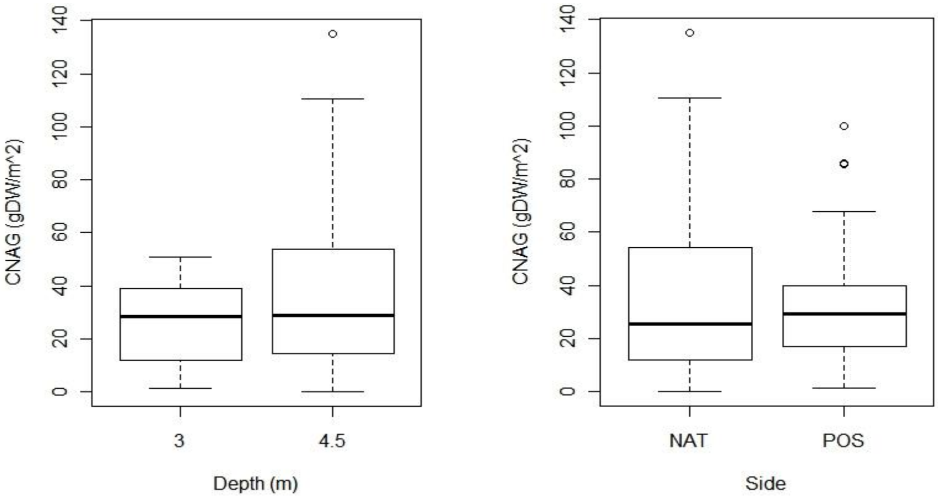

Figure 4.2.3.1.1. Dry aboveground biomass of *Cymodocea nodosa* at different depth (a) and side (b).

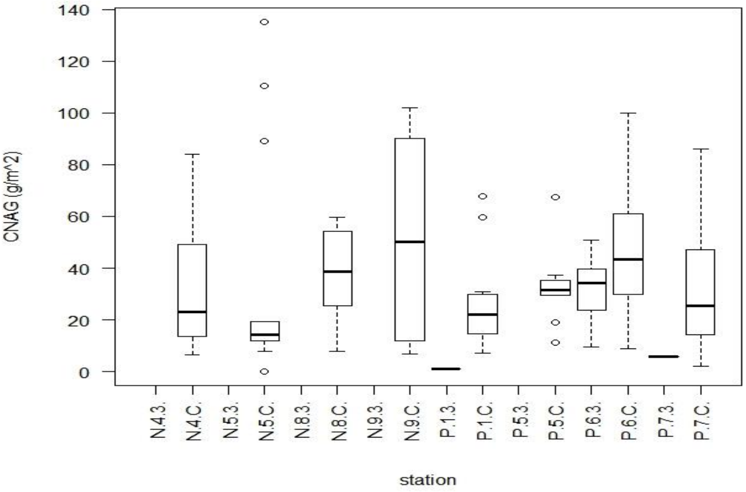

Figure 4.2.3.1.2. *Cymodocea nodosa* dry aboveground biomass by sampling sites.

Belowground biomass of *C. nodosa* (CNBG) ranged from 0.7 gdw/m^2 to 343.8 gdw/m^2. Mean value of belowground biomass was 132.1 ± 7.46 gdw/m^2. *Cymodocea nodosa* belowground biomass was significantly higher on Posedarje side ($p < 0.001$) but no significant difference at different depths was recorded ($p = 0.215$). No correlation between belowground biomass and sediment accumulation rate was found ($p = 0.749$).

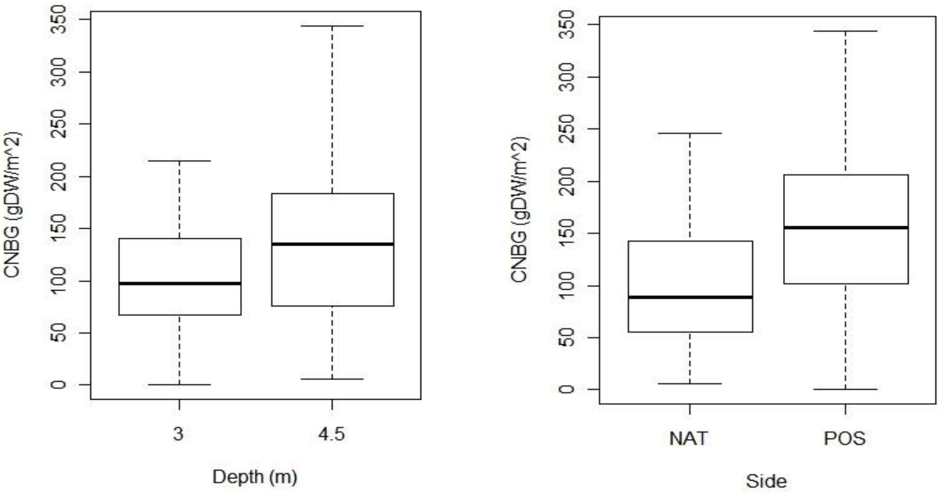

Figure 4.2.3.1.3. Belowground biomass of *Cymodocea nodosa* at different depth (a) and side (b).

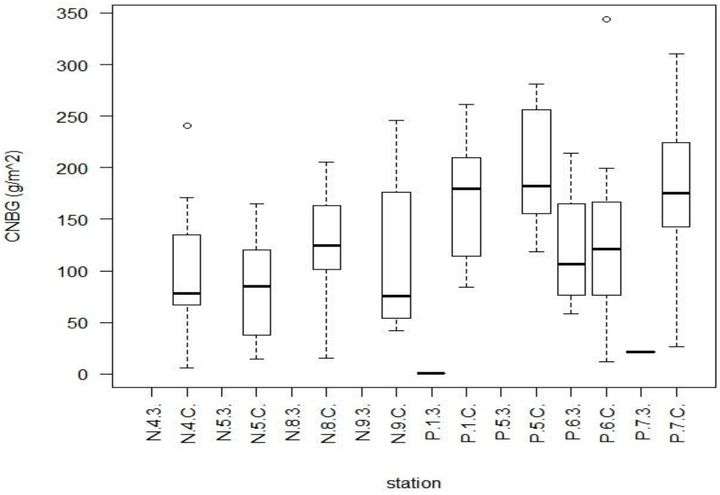

Figure 4.2.3.1.4. *Cymodocea nodosa* belowground biomass by sampling sites.

4.2.3.2. Shoot density, leaf length, leaf sheath length and internode length and width

Shoot density ranged from 56 shoots/m^2 to 2542 shoots/m^2. Mean value of shoot density was 775 ± 49 shoots/m^2. There was no significant difference of *Cymodocea nodosa* density (CND) on different sides (p = 0.062) or at different depths (p = 0.165). No correlation between density and sediment accumulation rate was found (p = 0.690).

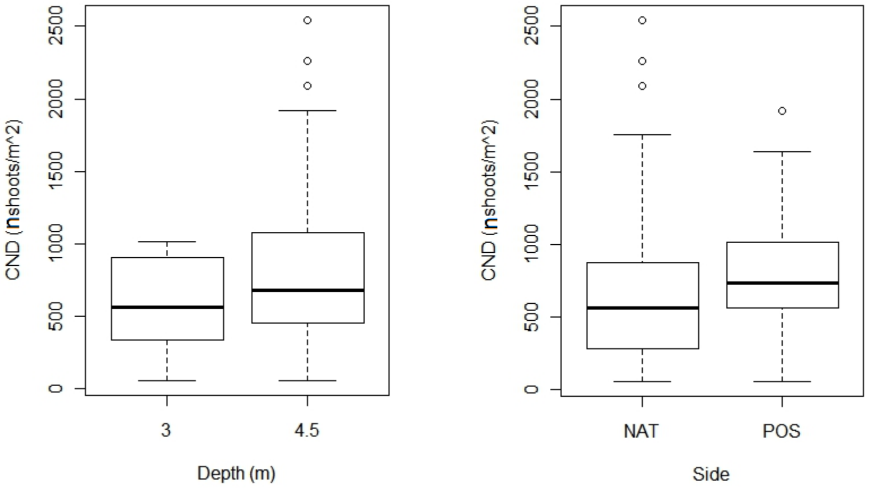

Figure 4.2.3.2.1. Shoot density of *Cymodocea nodosa* (CND) at different depth (a) and side (b).

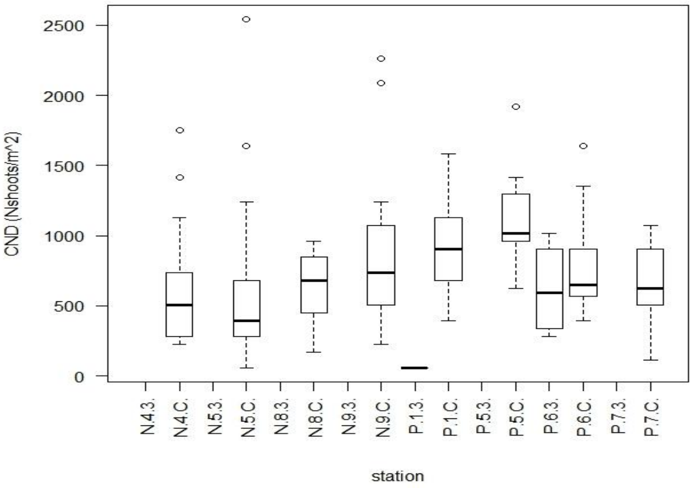

Figure 4.2.3.2.2. *Cymodocea nodosa* shoot density by sampling sites.

Leaf length ranged from 5.1 cm to 54.1 cm. Mean value of leaf length was 21.0 ± 0.43 cm. There was no significant difference ($p = 0.067$) of *C. nodosa* leaf length (CNLL) on different sides, but it was significantly higher on 3 meter depth ($p < 0.001$). No correlation between leaf length and sediment accumulation rate was found ($p = 0.336$).

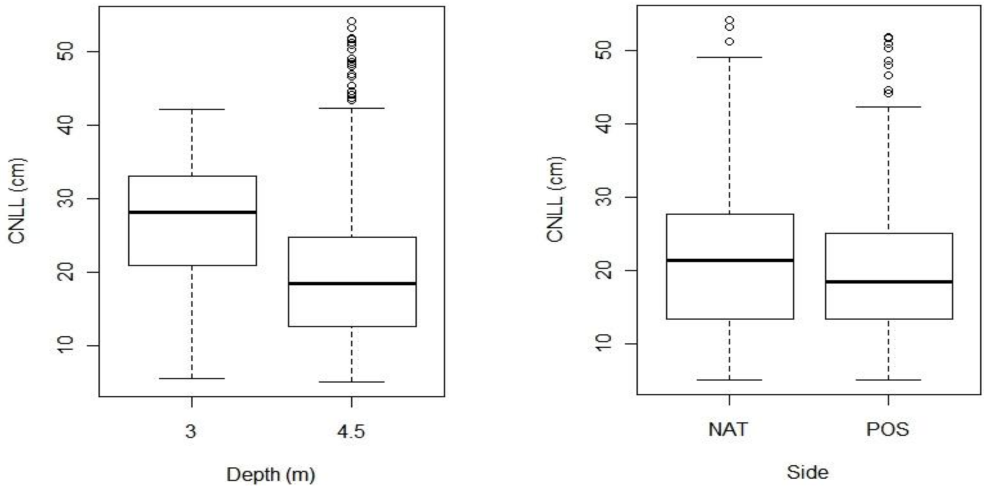

Figure 4.2.3.2.3. Leaf length of *Cymodocea nodosa* (CNLL) at different depth (a) and side (b).

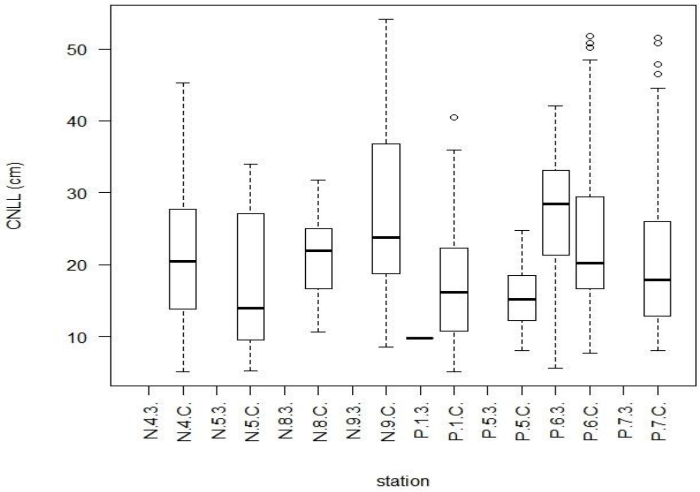

Figure 4.2.3.2.4. *Cymodocea nodosa* leaf length by sampling sites

Leaf sheath length ranged from 0.2 to 14.0. Mean value of leaf sheath length was 3.9 ± 0.09 cm. There was no significant difference of *C. nodosa* leaf sheath length (CNLSL) on different sides ($p = 0.079$), but it was significantly higher on 3 meter depth ($p < 0.001$). No correlation between leaf sheath length and sediment accumulation rate was found ($p = 0.515$).

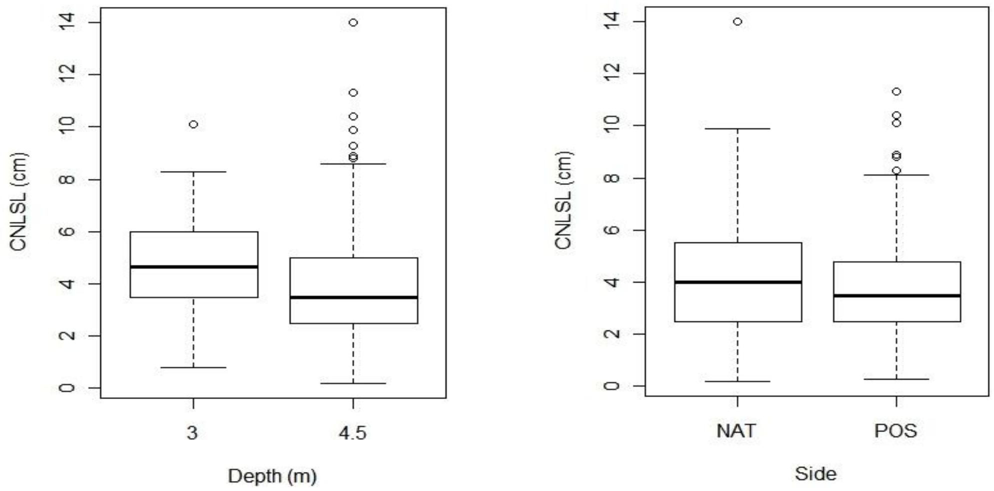

Figure 4.2.3.2.5. Leaf sheath length of *Cymodocea nodosa* (CNLSL) at different depths and sides.

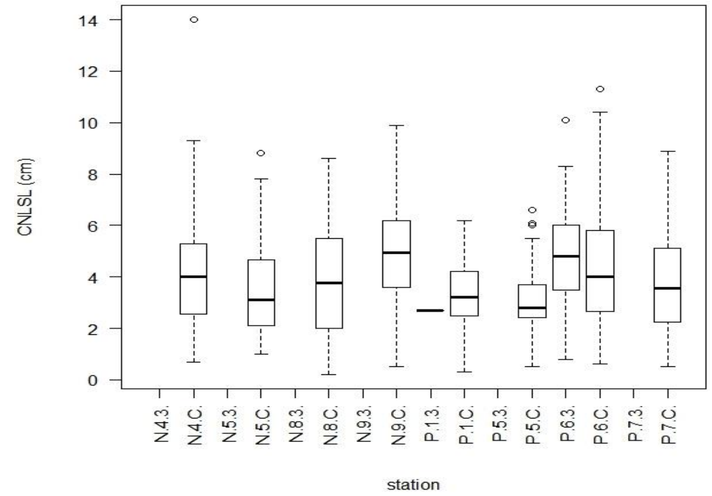

Figure 4.2.3.2.6. *Cymodocea nodosa* leaf sheath length by sampling sites

Horizontal internode length ranged from 0.1 cm to 7.4 cm with the mean length of 2.6 ± 0.07. Horizontal internodes of *C. nodosa* were significantly longer on natural side ($p < 0.001$) and 4.5 meter depth ($p < 0.001$). No correlation between horizontal internode length and sediment accumulation rate was found ($p = 0.626$).

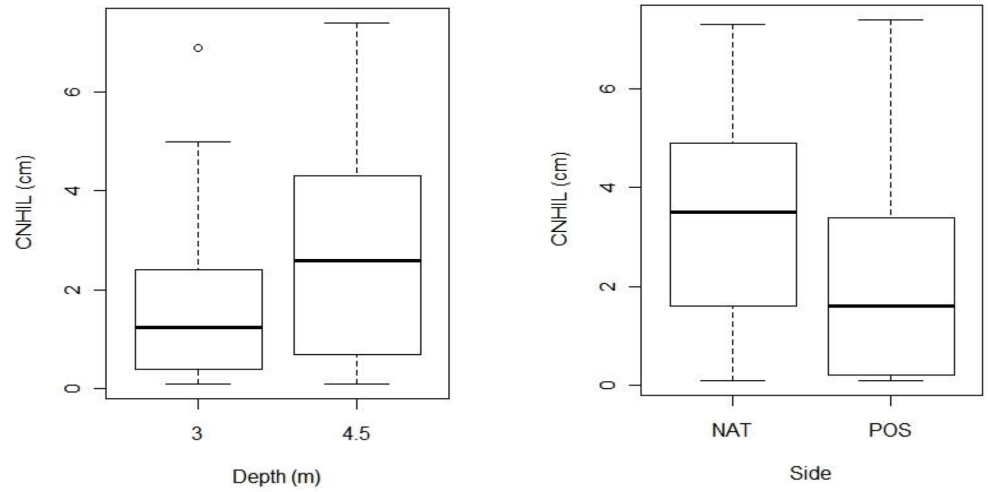

Figure 4.2.3.2.7. Horizontal internode length of *Cymodocea nodosa* (CNHIL) at different depth (a) and side (b).

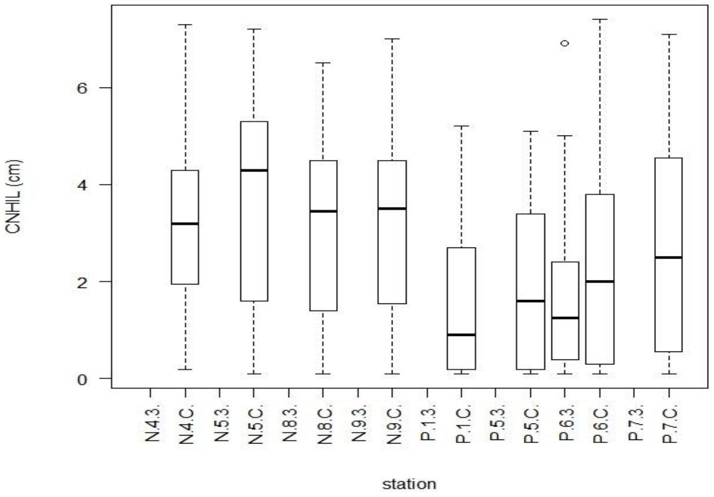

Figure 4.2.3.2.8. *Cymodocea nodosa* horizontal internode length by sampling sites

Vertical rhizome length (CNVRL) ranged from 0.5 cm to 8.1 cm with mean value 2.4 ± 0.09. *Cymodocea nodosa* vertical rhizomes were significantly longer on Posedarje side ($p < 0.001$), but no difference was found at different depths ($p = 0.185$). Mean length of vertical rhizome on natural side was 1.9 cm, while it was 2.6 cm on Posedarje side. No correlation between vertical rhizome length and sediment accumulation rate was found ($p = 0.244$).

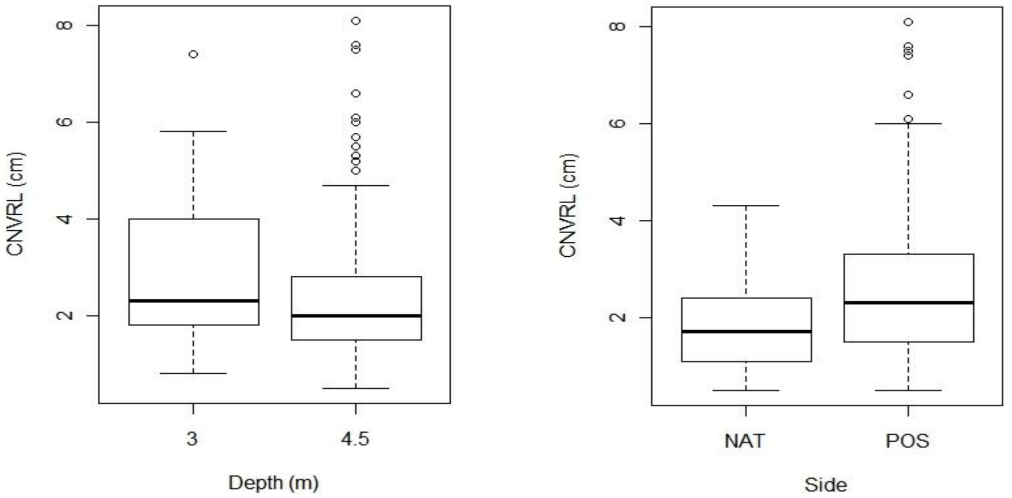

Figure 4.2.3.2.9. Vertical rhizome length of *Cymodocea nodosa* (CNVRL) at different depth (a) and side (b).

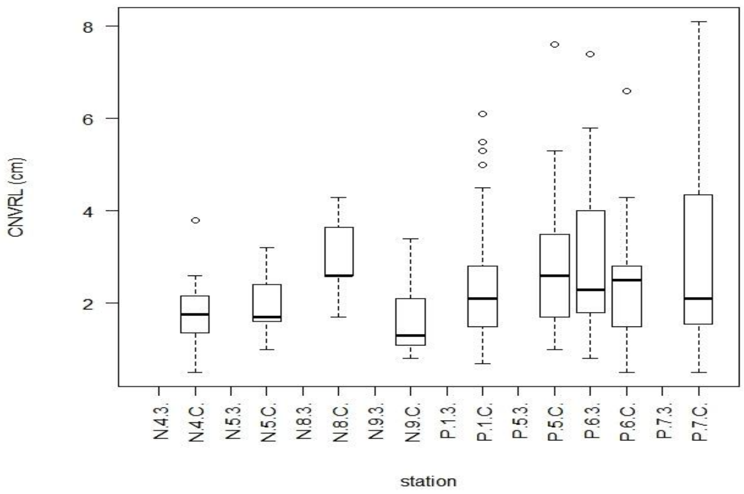

Figure 4.2.3.2.10. *Cymodocea nodosa* vertical rhizome length by sampling sites

Table 4.2.1.2.1. Morphological characteristics of *Cymodocea nodosa*. Mean values, standard error of the mean and number of samples are presented (CNAG – *C. nodosa* aboveground biomass, CNBG – *C. nodosa* belowground biomass, CND – *C. nodosa* shoot density, CNLL - *C. nodosa* leaf length, CNLSL - *C. nodosa* leaf sheath length, CNHIL - *C. nodosa* horizontal intenode length, CNVIL - *C. nodosa* vertical internode length).

	Natural			Posedarje		
	mean	SEM	n	mean	SEM	n
CNAG (gdw/m^2)	39.2	5.4	41	32.8	3.0	55
CNBG (gdw/m^2)	102.4	9.7	41	1538	10.4	55
CND (shoots/m^2)	738.4	91.4	41	804.6	52.2	55
CNLL (cm)	21.8	0.7	221	20.5	0.5	329
CNLSL (cm)	4.1	0.1	221	3.8	0.1	329
CNHIL (cm)	3.3	0.1	384	2.0	0.1	510

4.3. Sediment traps and sediment samples

4.3.1. Sediment accumulation rate from sediment traps

Sediment accumulation rate ranged from 19.3 gdw/m^{2}day to 177.9 gdw/m^{2}day with mean value of 65.1 ± 2.1 gdw/m^{2}day. Sediment accumulation rate (SAR) was significantly higher on natural side ($p < 0.001$), but no significant difference was found at different depths ($p = 0.080$).

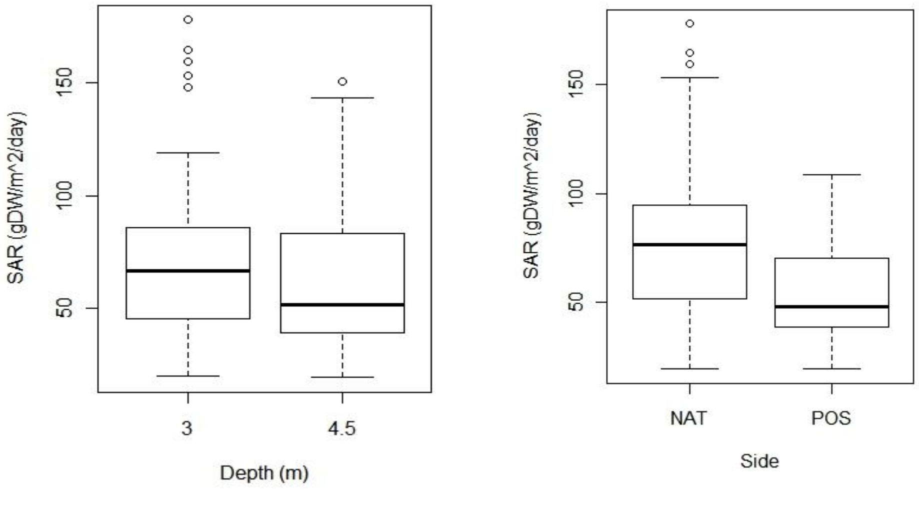

Figure 4.3.1.1. Sediment accumulation rate (SAR) at different depth (a) and side (b).

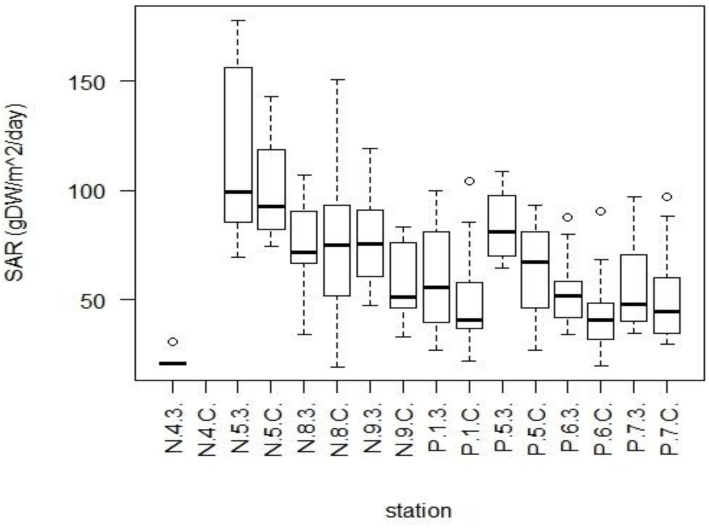

Figure 4.3.1.2. Sediment accumulation rate by sampling sites

4.3.2. Sediment organic matter content and granulometry of sediment samples

Sediment organic matter content (OC) ranged from 0.8 to 8.5%. Mean value of OC was 3.3 ± 0.28. Organic matter content was significantly higher on Posedarje side ($p < 0.001$), however no significant difference was found on different depths ($p = 0.842$). Correlation between organic matter content and sediment accumulation rate was found to be significantly moderate and negative ($p = 0.003$, rho = -0.45).

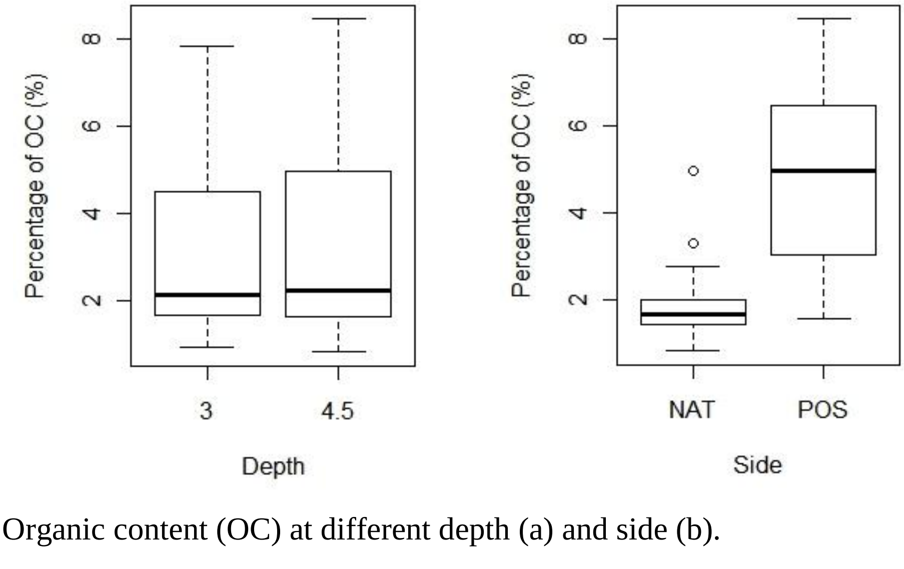

Figure 4.3.2.1. Organic content (OC) at different depth (a) and side (b).

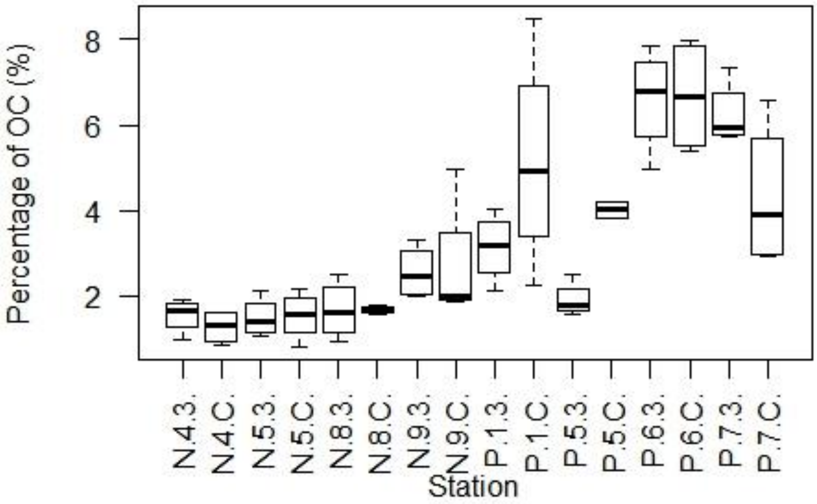

Figure 4.3.2.2. Organic content by sampling sites.

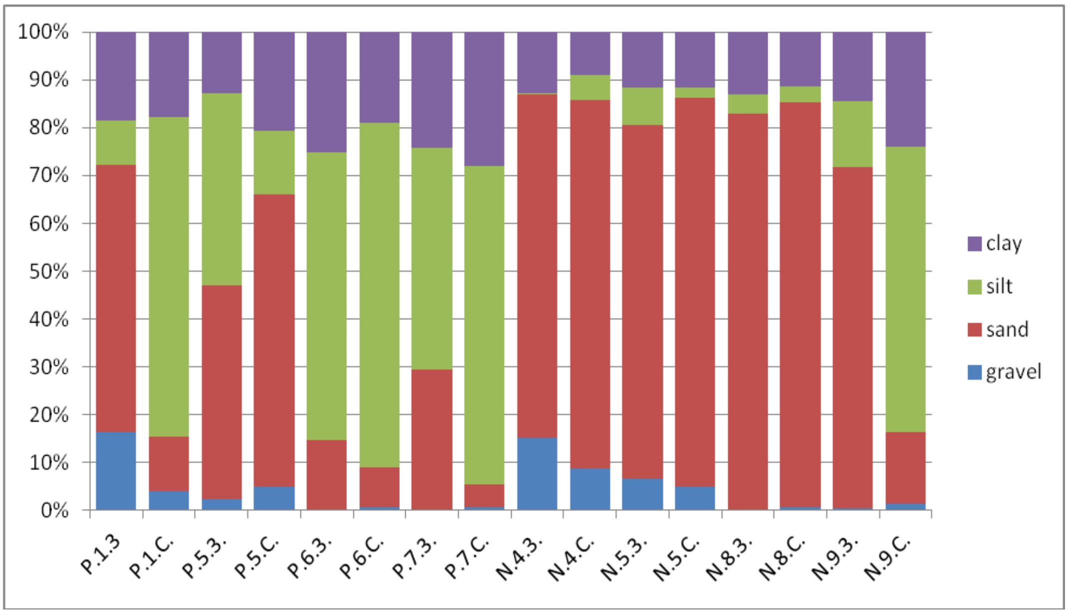

Figure 4.3.2.3. Percentage of different sediment types among sampling sites (P indicates sites on Posedarje side, and N on natural side)

Grain size analysis showed a difference in the distribution of different sediment grain sizes (Figure 4.3.2.3.) hence the percentage of clay, silt and sand showed significant differences on different sides. Percentage of clay (%) in samples ranged from 4.6 - 45.8 with mean of 18.9 (± 1.3). It was significantly higher on Posedarje side (*p* < 0.001), but there was no difference between depths (*p* = 0.584). Percentage of clay in sediment samples was negatively correlated with sediment accumulation rate (*p* = 0.035, rho = -0.326) hence it was decreasing with higher sediment accumulation.

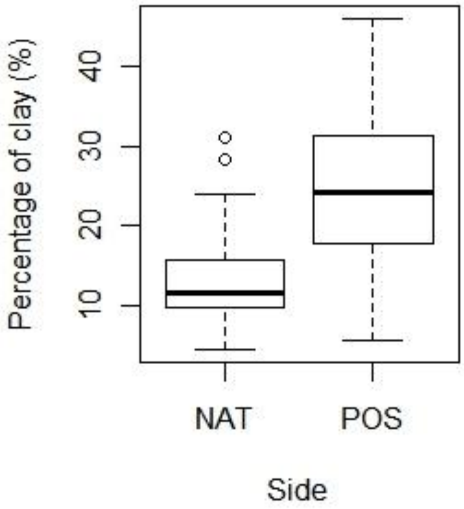

Figure 4.3.2.4. Percentage of clay (%) on different sides with significantly higher values on Posedarje side.

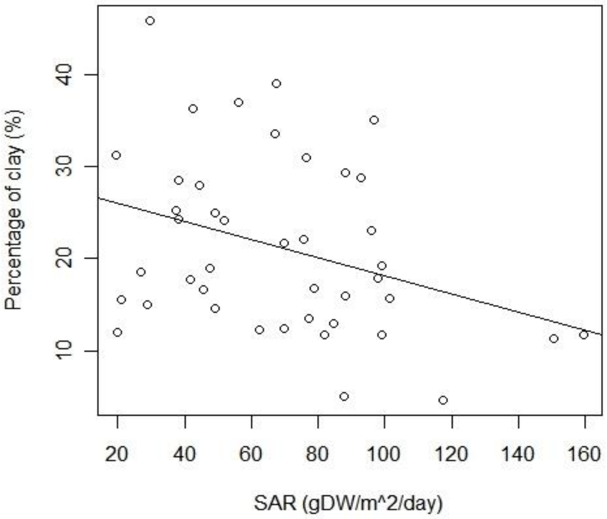

Figure 4.3.2.5. Correlation between percentage of clay (%) and sediment accumulation rate (SAR).

Percentage of silt (%) in samples ranged from 0.2 - 72.8 with mean of 22.0 (± 2.9). It was significantly higher on Posedarje side (*p* < 0.001), but there was no difference between depths (*p* = 0.162). Percentage of silt in sediment samples was negatively correlated with sediment accumulation rate (*p* = 0.001, rho = -0.471) and it was decreasing with the increase of sediment accumulation.

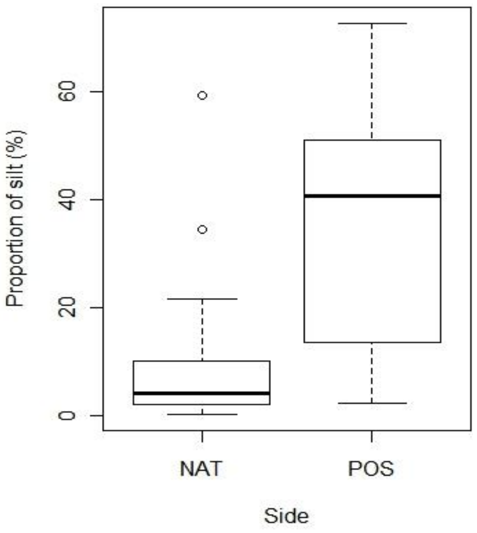

Figure 4.3.2.6. Percentage of silt (%) on different sides with significantly higher values on Posedarje side.

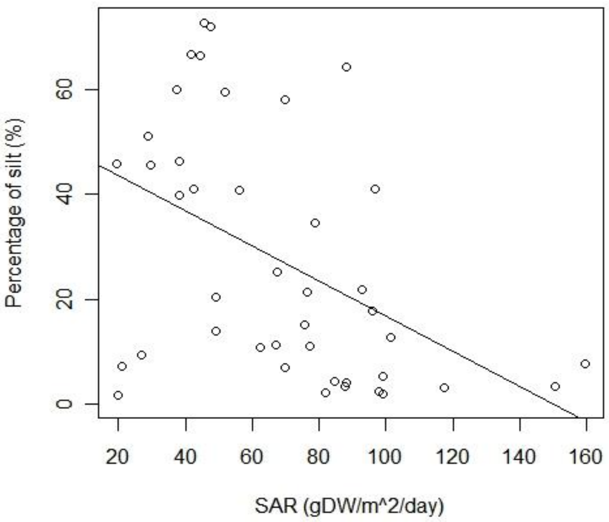

Figure 4.3.2.7. Correlation between percentage of silt (%) and sediment accumulation rate (SAR).

Percentage of sand (%) in samples ranged from 4.8 - 86.2 with mean of 52.8 (± 3.43). Percentage of sand was significantly higher on natural side ($p < 0.001$), but there was no difference between depths ($p = 0.371$). Percentage of sand in sediment samples was positively correlated with sediment accumulation rate ($p = 0.001$, rho = -0.479).

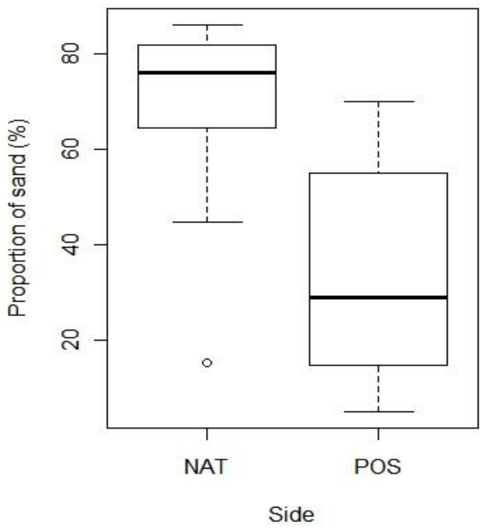

Figure 4.3.2.8. Percentage of sand (%) on different sides with significantly higher values on natural side.

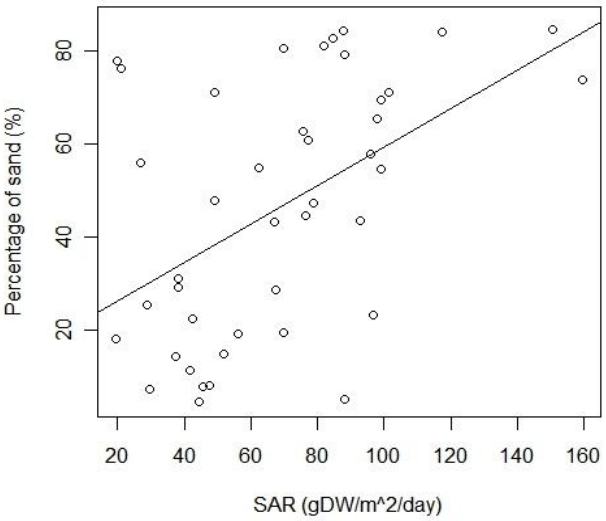

Figure 4.3.2.9. Correlation between percentage of sand (%) and sediment accumulation rate (SAR)

Percentage of gravel (%) in samples ranged from 0.1 - 31.8 with mean of 6.3 (± 0.92). Percentage of gravel was not significantly different on different sides (*p* = 0.773) neither on different depths (*p* = 0.549). Percentage of gravel in sediment samples was not significantly correlated with sediment accumulation rate (*p* = 0.472).

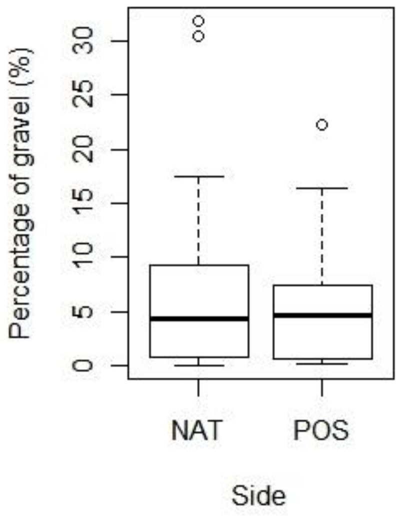

Figure 4.3.2.10. Percentage of gravel (%) on different sides

Table 4.3.2.1. Sediment accumulation rate (SAR), organic content (OC) and sediment grain size (clay, silt, sand, gravel) on different sides. Mean values, standard error of the mean and number of samples are presented.

	Natural			Posedarje		
	mean	SEM	n	mean	SEM	n
SAR (gdw/m^{2}day)	35.2	3.2	120	22.0	2.0	120
OC (%)	0.8	0.1	31	2.0	0.4	29
Clay (%)	6.4	1.1	31	9.8	1.8	29
Silt (%)	12.3	2.2	31	22.4	4.2	29
Sand (%)	15.8	2.8	31	22.0	4.1	29
Gravel (%)	8.2	1.5	31	5.8	1.1	29

5. DISCUSSION

5.1. Video monitoring

The videography method used in this research (Schultz 2008; Schultz et al. 2011) was able to detect changes in seagrass density and seagrass coverage on over 8800 m of transects. Besides this, it was also able to detect net sediment movement in the studied mixed seagrass meadow on the recorded transects. Accumulation and deposition of sediment was recorded for 2009/2010, while a minor erosion which occurred on natural side was recorded for 2010/2011. However, differences in sediment accumulation between two different time intervals were not significant. Previous studies (Schultz et al. 2011) showed that sediment movement in the Novigrad Sea is strongly influenced by wind activity. Wind generated waves cause sediment movement in the shallow depths (Luettich et al. 1990; Hoffman et al. 2008). The year 2010/2011 had more days with strong N and NE winds compared to 2009/2010 (Table 3.7.1.) hence this longer period of strong winds could cause recorded erosion on natural side (Table 4.1.1.3.) which is more exposed to winds from N and NE direction.

Additionally, on Posedarje side fewer transect meters with dense seagrass was recorded, compared to natural side which might be due to higher level of sediment accumulated in that area in the observed period. This observation is in line with existing literature which shows that seagrass species which form seagrass meadow from Novigrad Sea, as well as many other seagrass species (Cabaço et al. 2008), experience decrease of seagrass shoot density when exposed to sediment accumulation including *Z. marina*, *Z. noltei* and *C. nodosa*. Given that increased sediment deposition causes decrease in seagrass density and its mortality, it is likely that accumulated sediment caused this decrease of seagrass density. Species *Z. noltei* showed a decrease in shoot density when exposed to sediment burial (Cabaço & Santos 2007), while Han et al. (2012) showed that plants exposed to continuous burial have higher survival rate than those exposed to sudden burial. Increased shoot mortality due to sediment burial has been reported for *C. nodosa* which leads to decrease of shoot density (Marba & Duarte 1994). This result is in contrast to previous results from studied area. Namely, Schultz et al. (2011) found that *C. nodosa* increased its coverage in the area with higher level (15 cm) of accumulated sediment. In such conditions, new layer of accumulated sediment served as a new settlement ground for seagrass with better light conditions hence seagrass could move to light favorable conditions and increase their coverage and density. Perhaps, sediment accumulation in the studied period of this research was too high hence the seagrass could not surpass negative effect of accumulated sediment therefore decreased its density and experienced loss of 0.005 m_{sg}/m_{tr} in the whole time interval. However, our research did not separate different seagrass species as it was difficult to the observer to distinguish seagrass on a species level.

Net change from unconsolidated ground to seagrass was recorded both in 2009/2010 and 2010/2011. In the second time interval, between 2010 and 2011, this change was significant with higher loss of seagrass, which occurred under accumulation conditions hence it is likely that sediment movement is partially causing changes in seagrass distribution, together with some other factors e.g. eutrophication, competition.

Overall, this method recorded changes in net sediment movement, net seagrass density and change of ground type in two time intervals in Novigrad Sea. Decrease of seagrass density and loss of seagrass cover in 2010/2011 might be caused by sediment accumulation in studied area which is most likely generated by winds as mentioned in Schultz et al. (2011).

This research used videography method to monitor the area with several Natura 2000 habitats and the data exists for the period for 2009, 2010 and 2011. An outcome of this research is the collection of videos recorded which make a permanent archive of the sea bottom along recorded transects. Future monitoring can compare to these archives on details of seagrass distribution, cover, depth and sediment substrate and associated species e.g. *Pinna nobilis*, *Anguilla anguilla* at any time in the future hence the data collected can be used to help with the development of the management plan for this area.

The literature and previous research show the sensitivity of seagrass to sediment addition. Seagrass species are extremely important not only as a habitat for different marine species, but also as a carbon sink and seagrasses are able to mitigate climate change which, currently, is a major global issue and for that reason these habitats should be protected from future devastation. Moreover, all seagrass species found in the studied area are protected by the Ordinance on Strictly Protected Species (144/2013), therefore need to be protected from further loss and monitored according to Article 62., paragraph 3 of the Environmental Protection Act (NN 80/13). According to Schultz et al. (2015) this method is considered as “gold standard” for monitoring seagrasses. Recommendations of protection measures for above mentioned Natura 2000 habitats include avoidance and prohibition of coastal constructions and sediment addition in areas which contain such habitats. Areas containing seagrass recorded in this research can be considered in the future development plans for the study area and implement protection of seagrass species and above mentioned Natura 2000 habitats and help secure healthy ecosystem of Novigrad Sea for the- future. Healthy Novigrad Sea means health and wellbeing for local citizens who rely on it on several levels (fisheries, aquaculture, tourism).

5.2. Seagrass characteristics in relation to sediment accumulation rate and sediment characteristics

Studied seagrass bed consists of three different seagrass species which tolerate sediment burial differently (Cabaço et al. 2008). Hence, to show the link between seagrass and sedimentation conditions, seagrass will be discussed separately.

Both *Zostera* species found in Novigrad Sea were previously considered to have only horizontal rhizome with no ability to acclimate to sediment loading by vertical growth (Cabaço et al. 2008; Borum et al. 2004; Short & Coles 2001). Hence it was expected to have a lower shoot density and biomass in the area with higher sediment accumulation rate (Cabaço et al. 2008). However, the results showed the opposite situation for both species. *Zostera noltei* and *Zostera marina* aboveground biomass as well as their density had higher values on the area with higher sediment accumulation rate, furthermore, this was correlated with sediment accumulation rate for *Z. marina*. It is known that some seagrass species tolerate low to moderate levels of burial (e.g. *C. nodosa* tolerates burial up to 7 cm of sediment) and even increase their productivity and biomass under burial conditions (Marba & Duarte 1994; Han et al. 2012). In conditions of burial and accumulated sediment, deposited sediment raises the ground which seagrass can settle hence the seagrass can move to more preferable light conditions and inhabit previously deeper areas with lower light availability. According to Han et al. (2012), different intensity and frequency of burial or erosion can have different effects on the survival of *Z. noltei*. Sudden burial events had a stronger negative impact than continuous ones with much higher survival of *Z. noltei* under continuous sediment burial. This might be the case in the studied area, compared to sudden burial because in the case of experimental sudden burial of plants with high level of sediment, they experience high mortality (Marba & Duarte 1994; Cabaço & Santos 2007; Cabaço et al. 2008). Though Mills & Fonseca (2003) show the increase in *Z. marina* mortality due to sediment burial, they also found that the addition of sand to a level of 25% of plant height (4 cm sediment height) caused slightly higher productivity. Similar observation was recorded by Munkes et al. (2015) where there was a positive growth rate and increase in shoot density when *Z. marina* was experimentally suddenly buried by 5 cm of sediment, and levels higher than 5 cm caused high mortality. Schultz et al. (2011) showed that *C. nodosa* increased its abundance under moderate sedimentation level in the Novigrad Sea. Hence, even though *Z. noltei* and *Z. marina* were found in the area with higher sediment accumulation rate it might be that the sedimentation rate was still low enough not to cause their mortality and that these two seagrass species had enough time to adapt to these new conditions.

Wicks et al. (2009) showed that *Z. marina* had shorter leaves and longer roots in the area with higher hydrodynamic activity due to wind and waves, and with the sediment containing lower organic content hence suggested that these morphological features could improve anchoring capacity of seagrass roots as well as better withstand the drag exerted on the seagrass leaves. Species *Z. noltei* and *Z. marina* from Novigrad Sea that were found in the area with muddy sediment as well as higher organic content had lower belowground biomass indicating the acclimation on low hydrodynamic area. Both species had higher belowground biomass values in the area with higher sediment accumulation rate and coarse sediment grain size (sandy sediment) which indicates that these two species developed larger anchoring system to better cope with higher hydrodynamic activity. This was also found in *Z. noltei* from Cadiz Bay, Spain (Peralta et al. 2000; Peralta et al. 2005). Additional explanation for this might be related to higher organic contect as some seagrass species show higher allocation to leaf biomass relative to belowground biomass in the eutrophicated areas (Oliva et al. 2012). This needs to be more studied for this area.

Zostera noltei aboveground and belowground biomass was significantly higher on 3 meter depth when compared to biomass on 4.5 meter depth. In Novigrad Sea, this species occurs from the intertidal to approx. 4.2 meter depth (Schultz et al. 2011). Hence this difference in biomass might be due to the fact that 4.5 meter lower depth limit of this species hence it has lower biomass and density. This kind of vertical distribution of *Z. noltei* in Novigrad Sea is probably caused by differences in light availability on different depths and not by difference in sediment accumulation rate as the accumulation rate was not significantly different on different depths. *Zostera marina* occupies area from 1 to 5 meter depth, approx. Biomass and density were slightly higher at three meter depth when compared to 4.5 m but this difference was not significant.

Zostera noltei did not show any differences in the leaf length and leaf sheath length in correlation to sediment accumulation rate. This is in line with previous research which also did not show the difference in leaf length and leaf sheath length of this species under different sediment deposition conditions (Laugier et al. 1999; Cabaço & Santos 2007; Cabaço et al. 2008). Cabaço & Santos (2007) experimented with burial of *Z. noltei* with several burial levels, however there these parameters were not related. However, *Z. marina* had longer leaves and leaf sheath in the area with lower sediment accumulation rate. Increase of leaf length and leaf sheath length is known to be correlated with sediment burial and it has been reported for some seagrass species e.g. *C. nodosa* (Marba & Duarte 1994, Cabaço et al. 2008) and *Posidonia australis* (Cabaço et al. 2008). Burial may also increase the probability of exposure of the leaf meristems, which may be buried in the sediments, to anoxic conditions, which has been shown to lead to seagrass mortality (Borum et al., 2005). Burial affects seagrass also by reducing the surface of photosynthetic tissue hence increase of leaf length and leaf sheath length brings seagrass to better light conditions. But, this direct effect of burial might not be the case with *Z. marina* in this research. *Zostera marina* with significantly longer leaf and leaf sheath (Figure 4.2.2.2.3.;) Figure 4.2.2.2.5.) was present in the area with higher organic matter content, and higher silt and clay content in the sediment (Figure 4.3.2.1.; Figure 4.3.2.4.; Figure 4.3.2.6.) while *Z. marina* with shorter leaf and leaf sheath was present in the area with higher sand content and lower organic matter content in the sediment. According to Boese et al. (2008), *Z. marina* is relatively tolerant of hypoxic sediment conditions as it transports oxygen from leaves to roots. Additionally, increase of *Z. noltei* leaf sheath length correlated with the increase of organic matter content. Namely, the explanation for this might be found in the fact that in the conditions of low hydrodynamic activity, small sediment particles deposit on the bottom, hence the content of silt and clay increases in the sediment and this is, again, correlated with the increase of organic matter content. High organic matter in the sediment reduces the concentration of oxygen hence and more of 5% of organic content in the sediment can cause the absence of seagrass (Koch 2001). In accordance with the study made by Koch et al. (2001), presumably, seagrass in such conditions of elevated organic content, increase their leaf length to increase the photosynthetic area which can then produce more oxygen that can be transported into the roots, hence overcome the negative influence of high organic content in the sediment. This way seagrass can contribute to the improvement of the water quality.

Additional finding of this study might also better explain the condition of *Zostera* species in the area with higher sediment accumulation rate. Namely, many seagrass species are known to possess both, horizontal and vertical growth. Only one of three seagrass species present in Novigrad Sea, *C. nodo*sa, in the past was considered to develop vertical and horizontal rhizome. *Zostera noltei* and *Z. marina* are considered to be species without a possibility of vertical growth since they lack vertical rhizome. However, Brun et al. (2005) reported the existence of vertical rhizome in genus *Zostera* for the first time and it was reported for *Z. noltei*. Never before, or after, a vertical rhizome in *Z. noltei* was reported, until now. Moreover, vertical rhizome was found in *Z. marina* as well, for the first time, according to literature. Orthotropic rhizome was found in *Z. noltei* from Novigrad Sea. It consisted of many small, short internodes indicating low sediment accumulation rate. The same type of short internodes was found in Cadiz Bay and it seemed to be triggered by sediment burial and erosion events (Brun et al. 2005). Vertical rhizomes of *Z. noltei* from Cadiz Bay had internodes 6.1 cm long indicating higher sediment accretion rates in the area. The lack of such long internodes in samples from Novigrad Sea (max. vertical internode length = 1 cm) indicates that sediment in this area is deposited in lower rate. In addition, vertical rhizome could enable *Z. noltei* to tolerate sediment addition and survive this kind of environmental disturbance. Even though vertical rhizome in *Z. noltei* was found in the area of lower and higher accumulation rate, length of vertical internodes was significantly higher on natural side which had higher accumulation rate. This can be explained by sediment accumulation (35.2 gdw/m^{2}day) which could have induced the development of vertical growth with longer vertical internodes in *Z. noltei*.

This study reports vertical rhizomes in the seagrass *Z. marina*, for the first time according to literature. Vertical rhizomes were defined as an underground stem that 1) produces shoots and roots, and 2) is oriented orthogonal to the plane of the sediment surface and the plane of the horizontal rhizome mat. Vertical internodes of *Z. marina* were much shorter then horizontal internodes, following the similar pattern as in *Z. noltei* with vertical rhizome consisting out of many short internodes indicating slow sediment accumulation (Brun et al. 2005). Vertical rhizomes in seagrasses are widely interpreted as adaptations for survival of burial, and experimental studies have shown that vertical rhizome growth can be triggered by burial. Duarte et al. (1997) show that all seagrass species tested in the Philippines, except *Cymodocea serrulata* increased their vertical growth significantly after sediment addition, and Schultz et al. (2011) showed that *C. nodosa* increased its abundance under moderate (10-15 cm) sedimentation level in the Novigrad Sea. *Cymodocea nodosa* showed vertical growth when exposed to intermediate burial of c. 4 cm, and there was a bell-shaped relationship between sedimentation level and the performance of the seedlings, with maximum growth response at intermediate burial of c. 4 cm (Marba and Duarte 1994). Seagrasses without vertical rhizome growth can sometimes withstand burial after rearranging the position of horizontal rhizomes (genus *Zostera*, *Halophila*, *Enhalus*) or by reaching a large size (genus *Enhalus*); however, the ability to produce vertical rhizomes increases the capacity of seagrasses to survive sediment burial (Vermaat et al. 1997). Overall, large seagrass species with vertical rhizomes show more evident burial tolerance, while small seagrasses lacking vertical rhizomes are more sensitive (Cabaço et al. 2008).

The observed vertical growth of *Z. noltei* and *Z. marina* might be triggered by sediment accumulation documented at the study site (Schultz et al. 2011). These species are located in the area exposed to water movement caused by the E-NE bora which can cause substantial sediment movement during bora storms. During these storms, steep spilling breakers can erode the sediment, and move this eroded sediment into the area* where *Z. marina* and *Z. noltei* occur. Additional source of sediment is a stream which drains nearby farmland and enters the estuary few hundred meters from the collection sites. Accordingly, these plants may be subject to regular erosion and burial under several cm of sediment during periods of hours to days, and strong natural selection for tolerance of burial.

There are several possible explanations for the absence of previous records of vertical rhizomes in *Z. marina* and *Z. noltei*. Previous experimental studies might not have reproduced the precise natural conditions that stimulated such growth in this study. Sediment accumulation from natural processes as described above is more gradual than sudden burial during artificial experiments that have so far failed to demonstrate a vertical growth response in *Z. marina* (Mills and Fonseca 2003) and *Z. noltei* (Cabaço and Santos 2007; Han et al. 2012). An experiment with continuous sediment addition also failed to induce vertical growth in *Z. noltei* (Han et al. 2012). Sudden sediment burial with two different sediment types showed increased mortality and decreased productivity of *Z. marina* on the east US coast (Mills and Fonseca 2003). Additionally, the response to burial may be different depending on whether the seagrass sample is a single shoot versus an integrated system of ramets (meadow). The latter might be better able to reallocate resources to support shifts in rhizome orientation than the single shoot that is often used in experimental studies (Marbà and Duarte 1994, Mills and Fonseca 2003). Furthermore, genetic variation in the ability to produce vertical rhizomes may exist in *Z. marina*. Local adaptation has been demonstrated in *Z. marina* in the rates of growth and of biomass accumulation (Hammerli and Reusch 2002). High genetic diversity of *Z. noltei* allowed this species to persist over a long period of time in Wadden Sea (Zipperle et al. 2009). If directional selection for burial tolerance is geographically variable, and fitness tradeoffs exist, then many populations of these species may not have the ability to produce vertical rhizomes. In the Novigrad Sea, the region most likely to experience such selection is the region exposed to the steepest waves, where most sediment movement is expected. That region is the study site, the farthest west portion of the Novigrad Sea with maximum fetch for the E-NE bora winds. Even though it was not significant, vertical internodes were mostly found in the area with higher sediment accumulation rate.

Vertical rhizome growth in the genus *Zostera* has been recorded only by Brun et al. (2005), who found vertical rhizomes in *Z. noltei* on the Iberian Peninsula in locations subject to sediment movement in response to episodic storms, similar to our study site. In the study of Brun et al. (2005), vertical rhizomes reverted to horizontal rhizomes once the meristem reached the sediment surface. However, some of our samples of *Z. marina* and *Z. noltei* had green shoots at the apical node of the vertical rhizome, and none showed any shift of growth to a horizontal direction. The short vertical internodes recorded indicate slow accumulation rates. Gradual sediment accumulation might provide sufficient time for plants to initiate and carry out the developmental response necessary for the production of vertical rhizomes. Interestingly, Han et al. (2012) were unable to stimulate vertical growth in *Z. noltei* from the Scheldt estuary (SW Netherlands) under experimental conditions, which might be due to the short experimental time frame (four weeks).

In conclusion, we found vertical rhizomes in *Z. marina* and *Z. noltei* at a study site expected to experience episodic burial under sediment moved during strong storm activity. We interpret this as local adaptation for burial tolerance in this seagrass population.

Interestingly, *C. nodosa* did not show any significant difference in aboveground biomass on different areas with different sediment accumulation rate and depths (Figure 4.2.3.1.1.), while belowground biomass was the same on two depths but it was higher in the area with lower sediment accumulation rate (Figure 4.2.3.1.3.). Leaf length and leaf sheath length showed no difference between differemt sides while they were longer at 3 meter depth which might be due to better light conditions. Vertical internodes were longer on Posedarje side but it was not correlated with sediment accumulation rate. Additionally, none of the morphological characteristics observed (leaf length, leaf sheath length, horizontal internode length, vertical rhizome length) showed any significant difference in correlation to sediment accumulation rate neither sediment grain size. *Cymodocea nodosa* is the most tolerant species to sediment burial according to Cabaço et al. 2008) of all species found in Novigrad Sea. Hence, it was assumed that this species will show the difference in typical responses to sediment burial like vertical rhizome length, leaf and leaf sheath length as well as biomass or density in relation to sediment accumulation rate or at least sediment grain size which also indicates the difference in hydrodynamic activities. However, *C. nodosa* failed to show these indicators. Perhaps, the status of *C. nodosa* in Novigrad Sea is controlled by some other factors, and not sediment accumulation rate or grain size. The area with lower sediment accumulation rate is situated right next to the small town of Posedarje which has no sewage treatment hence the concentration of nutrients is likely to be quite higher than in the area with higher sediment accumulation rate which is natural and not populated. Perhaps the presence of nutrients caused the increase in shoot density on Posedarje side as nutrients stimulate seagrass growth (Cabaço et al. 2013) as the shoot density was higher on Posedarje side, even though not significantly. Leaf length and leaf sheath length were higher at 3 meter depth compared to 4.5 meter depth. This can be explained by better light conditions in the shallower depth. Namely, *C. nodosa* in Novigrad Sea occurs from approximately 3-6 meter depth with longer leaves at shallower depth (personal observation). Hence this difference in sampling depth could cause the difference in light conditions which cause the difference in leaf and leaf sheath length with better developed leaves in lower depth with better light conditions. This finding is in contrast to research done by Terrados (1997) who did not find the difference in the leaf and leaf sheath length when experimentally illuminated the meristem. *Cymodocea nodosa* horizontal internode length was significantly higher on natural side and at 4.5 meter depth, and *C. nodosa* vertical rhizome length was higher on Posedarje side, the area with lower sediment accumulation rate. These results were completely unexpected and they contradict our hypotheses. It is likely that the explanation for this probably lies in the influence of some other factors which were not included in this research, hence need to be examined in the future research on this species in this area. This is needed to explain and to better understand what drives *C. nodosa* distribution and differences of morphological parameters in western part of Novigrad Sea.

Research performed for this thesis focused on the effect of sedimentation on seagrassses in Novigrad Sea as one of the factors effecting them. Sediment dynamic processes are one of the factors affecting seagrass habitat in Novigrad Sea and additional factors need to be considered when evaluating the effect of sedimentation on seagrass in this area.

6. CONCLUSIONS

This thesis contributes to better understanding of the condition of mixed seagrass bed in western part of Novigrad Sea, eastern Adriatic under various conditions of sedimentation. Videography method once again proved to be a successful method used to detect net sediment movement and changes in seagrass density and ground cover. Additionally, new and rare morphological traits were discovered in genus *Zostera*. Studied area is a Natura 2000 site hence the data gathered by this research will help to better govern, protect and monitor seagrass meadows in Novigrad Sea and to be able to detect changes due to anthropogenic influence, climate change and other natural disturbances.

The conducted research resulted in following conclusions:

- videography method used in this research successfully recorded net sediment movement as well as change in seagrass density and ground cover in 2009/2010 and 2010/2011,
- sediment movement is partially causing changes in seagrass distribution in the studied area,
- aboveground biomass of seagrass samples collected was higher in the area with higher sediment accumulation rate hence it is possible that this rate was not too high to cause mortality of seagrass and seagrass could adapt to these conditions,
- seagrass samples collected in the area with higher sediment accumulation rate showed higher belowground biomass which is consistent with the observation (Wicks et al. 2009) that seagrass develop large anchoring system to cope with strong currents,
- higher biomass of *Zostera noltei* at 3 meter depth is likely to be caused by better light conditions than at 4.5 meter depth as at this depth *Z. noltei* is at its lower depth limit,
- *Zostera noltei* did not show any difference in its leaf length and leaf sheath length in relation to sediment accumulation rate which is in line with the research done by Cabaço and Santos (2007),
- significantly longer leaves and leaf sheath of *Zostera marina* in the area with higher organic matter content and higher silt and clay content is consistent with the observation (Koch 2001) that leaves increase their photosynthetic area in response to low oxygen in sediments,
- vertical rhizomes found in *Zostera marina* and *Zostera noltei* were probably induced by sediment burial in the studied area caused by strong E-NE winds and this morphological

feature can be interpreted as a local adaptation for burial tolerance of this seagrass population,

- *Cymodocea nodosa* did not show typical effects of sediment burial such as longer vertical rhizome, decrease of leaf length, increase of leaf sheath length or decrease of biomass in relation to sediment accumulation rate which indicates that some other factors are controlling this seagrass species in the studied area.

7. LITERATURE

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8. PROŠIRENI SAŽETAK

UVOD

Morske cvjetnice su biljke prilagođene na život u moru, naseljavaju pjeskovita i muljevita dna gotovo svih svjetskih mora (Short & Wyllie-Echeverria 1996; Short & Coles 2001; Vermaat 1997). Morske cvjetnice značajne su kao primarni proizvođači, dio su temelja obalne hranidbene mreže, sudjeluju i u procesu kruženja hranjiva koji bi inače ostali neiskorišteni u sedimentu. Neprocjenjiva je njihova uloga kao stanište, služe kao prostor za rast juvenilnih stadija mnogih kralješnjaka i beskralješnjaka, stabiliziraju sediment te štite obalu od erozije (Larkum et al. 2006, Orth et al. 2006). Važnost ovog staništa je još više porasla zadnjih godina zbog iznimne mogućnosti morskih cvjetnica da apsorbiraju ugljik te na taj način djeluju kao spremište ugljika. Na ovaj način, morske cvjetnice uklanjaju CO_2 iz atmosfere te doprinose ublažavanju klimatskih promjena. Iako pokrivaju tek 0,2% svjetskih mora, naselja morskih cvjetnica zadržavaju otprilike 10% godišnje količine ugljika koji se nalazi u oceanima (Fourquearan et al. 2012).

Postoji otprilike 60 različitih vrsta morskih cvjetnica te su one globalno rasprostranjene. Podijeljene su u 13 rodova i 5 obitelji (Short & Coles 2001). Većinom su to morski organizmi, ali neke od njih mogu preživjeti različite uvjete, od slatkovodnih do hipersalinih (Short & Coles 2001).

Naselja morskih cvjetnica drastično su smanjena na globalnoj razini i to za preko 30% od 1879.godine (Waycott et al. 2009). Daljnji nestanak cvjetnica je prvenstveno uzrokovan ljudskim djelovanjem putem eutrofikacije i sedimentacije (Walker et al. 2006; Cabaço et al. 2008). Svaka aktivnost koja mijenja lokalne uvjete hidrodinamike ili količinu sedimenta uzrokovat će i promjene u količini i smjeru premještanja sedimenta na lokalnoj razini te time dolazi i do promjena uvjeta potrebnih za opstanak morskih cvjetnica. Pod spomenute aktivnosti spadaju bilo kakvi radovi u obalnom područje npr. luke, marine, lukobrani, održavanje plaža te korištenje vodenog područje na bilo koji način koji mijenja stopu sedimentacije.

Na dinamiku sedimenta utječu i biotički i abiotički procesi koji se odvijaju na različitim prostornim i vremenskim skalama kao što su stalno prisutni valovi uzrokovani vjetrom, plimne struje i klimatske promjene. Takvi procesi mijenjaju stanište morskih cvjetnica mijenjajući turbiditet, veličinu sedimenta, kemijska i fizikalna svojstva sedimenta te stopu akumulacije i erozije sedimenta (Koch 2001).

Ovi procesi mogu u potpunosti uzrokovati propast i nestanak naselja morskih cvjetnica zatrpavanjem ili erozijom (Duarte et al. 1997; Manzanera et al. 1998). Međutim male ili postepene promjene u sedimentaciji mogu potaknuti promjene koje dovode do prilagodbe na novonastale uvjete kao npr. promjene u rastu i diferencijaciji dijelova biljke koji omogućavaju opstanak postojeće populacije (Duarte et al. 1997; Frederiksen et al. 2004). Pretpostavlja se da su ovakvi plastični odgovori u rastu morskih cvjetnica, evolucijski odgovori na selekciju u uvjetima zatrpavanja ili erozije u staništu sa izraženom dinamikom sedimentacije.

U hrvatskom dijelu Jadranskog mora postoje četiri vrste morskih cvjetnica: *Posidonia oceanica* (Linnaeus) Delile, *Zostera marina* Linnaeus, *Zostera noltei* Hornemann i *Cymodocea nodosa* (Ucria) Ascherson). Navedene vrste zaštićene su prema Pravilniku o strogo zaštićenim vrstama (Narodne novine 144/13).

Svrha i ciljevi istraživanja. Unatoč iznimnoj ekološkoj važnosti morskih cvjetnica, nedostaju podaci o interakciji morskih cvjetnica i dinamike sedimenta u istočnom dijelu Jadrana, uključujući Novigradsko more. Glavni cilj ovog istraživanja je pridonijeti boljem poznavanju međusobne povezanosti taloženja sedimenta i morskih cvjetnica u prirodnim uvjetima. Ovo istraživanje usmjereno je na uočavanje spomenute interakcije između morskih cvjetnica i sedimenta i promjene u naselju morskih cvjetnica upotrebom metode DGPS videografije (Schultz 2008) u kombinaciji sa uzorkovanjem morskih cvjetnica i sedimenta. Nadalje, usmjerava se i na otkrivanje utjecaja sedimentacije na morske cvjetnice kao i gustoću morskih cvjetnica, biomasu, oblike rasta rizoma te morfološke osobine kao što su (duljina lista, duljina lisne ovojnice, duljina internodija) koje mogu uputiti na odgovor cvjetnica na uvjete zatrpavanja ili erozije.

Površina koju pokrivaju staništa morskih cvjetnica u svijetu smanjila se je za 30% od 1879.g. (Waycott i sur. 2009) i daljnje propadanje ovih staništa uzrokovano je najčešće antropogenim djelovanjem poput eutrofikacije i sedimentacije (Short & Wyllie-Echeverria 1996; Orth i sur. 2006; Walker i sur. 2006; Cabaço i sur. 2008). Značajna dinamika sedimenta koja podrazumijeva prekomjerno zatrpavanje i eroziju je jedan od glavnih uzroka gubitka morskih cvjetnica (Cabaço i sur. 2008). Osim toga, u ovo istraživanje uključene su tri od četiri vrste morskih cvjetnica: *Z. marina*, *Z. noltei* i *C. nodosa* koje su prisutne u Novigradskom moru koje spada u Natura 2000 područje stoga rezultati ovog istraživanja mogu pridonijeti i boljem upravljanju ovim područjem.

Ciljevi ovog istraživanja su:

- upotreba metode DGPS videografije u svrhu otkrivanja promjena u pokrovu dna morskim cvjetnicama i u gustoći naselja morskih cvjetnica,
- upotreba metode DGPS videografije u svrhu otkrivanja promjena u taloženju sedimenta (akumulacija, erozija),
- utvrditi povezanost promjene pokrova na morskom dnu i promjena gustoće cvjetnica s akumulacijom sedimenta,
- utvrditi postoji li razlika u biomasi i morfološkim karakteristikama (dužina lista, dužina lisne ovojnice, duljina internodija) na različitim dubinama i stranama obale i jesu li razlike navedenih osobina povezane sa stopom akumulacije sedimenta.

MATERIJAL I METODE

Područje istraživanja. Istraživanje je provedeno u zapadnom dijelu Novigradskom moru koje je u cijelosti estuarij rijeke Zrmanje. Novigradsko more povezano je preko Masleničkog kanala s Velebitskim kanalom. Ovo područje u potpunosti je izloženo buri i sjevernim vjetrovima te premještanju velike količine sedimenta iz smjera sjeveroistoka prema jugozapadu tijekom nevremena. To tijekom vremena rezultira postepenim povišenjem morskog dna te povećanjem osvijetljene površine pogodne za naseljavanje morskih cvjetnica duž zapadnog i jugozapadnog kraja (Schultz i sur. 2011). Na ovom području nalazi se potok Bašćica koji se u more ulijeva na zapadnom dijelu estuarija, nekoliko stotina metara od istraživanih lokacija. Salinitet na ovom području je od 10 do 30 PSU (Schultz et al. 2011), a temperatura estuarija između 6,7 i 26,6 °C (Viličić 2011). Na istraživanom području prisutne su tri vrste morskih cvjetnica: *Zostera noltei* koja prevladava u zoni mediolitorala do otprilike 3 metra, *Zostera marina* koja se nalazi na dubini od otprilike 1 do 5 metara te *Cymodocea nodosa* koja se nalazi na najdubljem dijelu rasprostranjenosti morskih cvjetnica u ovom područje, od otprilike 3 do 6,6 metara. Livade su uronjene u more i izložene utjecaju sjevernog i sjeveroistočnog vjetra koji uzrokuju značajno pomicanje sedimenta. Najbliži anemometar bilježi udare vjetra od 60 m s^{-1} (Bajić 2003) za vrijeme bure. Snimani transekti i lokacije uzorkovanja smješteni su na sjevernoj (Posedarje) i južnoj (prirodnoj) strani uvale. Na sjevernoj strani nalazi se naselje s otprilike 1300 stanovnika i bez kanalizacijskog sustava, dok je južna strana nenaseljena i izložena buri. Na istraživanom području zabilježeno je nekoliko Natura 2000 staništa:

1. Pješčana dna trajno prekrivena morem (Natura 2000 kod: 1110)

a. G.3.2.2.1. Asocijacija s vrstom *Cymodocea nodosa*

2. Obalne lagune (Natura 2000 kod: 1150)
a. G.3.1.1.4. Asocijacija s vrstom *Zostera noltii* u eurihalinom i euritermnom okolišu (nacionalna klasifikacija staništa)
b. G.3.1.1.5. Asocijacija s vrstom *Zostera marina* u eurihalinom i euritermnom okolišu (nacionalna klasifikacija staništa).

Metoda DGPS videografije. Za potrebe istraživanja snimalo se 20 linearnih transekata okomitih na liniju obale, u lipnju 2009, 2010 i 2011 godine od površine do dubine na kojoj prestaju morske cvjetnice, otprilike 6,6 metara. Monitoring se provodio iz kajaka pri čemu je video kamera bila spuštena u more, otprilike 0,5 do 1 metar iznad dna (ovisno o vrsti dna i pokrova na dnu). Brzina kretanja bila je oko 0,5 m/s, a osvjetljenje je bilo dnevno. Dubina je očitavana svake dvije sekunde, a GPS položaj se bilježio cijelo vrijeme kretanja. Diferencijalni GPS odlikuje se centimetarskom preciznošću što su pokazala i testiranja (Dauwalter i sur. 2006). Monitoring se vršio za mirnog vremena i mirnog mora.

Analiza video snimaka. Video snimke pokazuju tip morskog dna i pokrov na njemu zajedno s podacima o dubini, brzini kretanja, GPS položaja te vremenu i datumu snimanja. Zabilježeno je nekoliko različitih tipova dna: kamenito, nekompaktno (pijesak, šljunak), prekriveno algama i prekriveno morskim cvjetnicama. U kategoriji dna prekrivenog morskim cvjetnicama analizirane su dvije kategorije gustoće: rijetke (1-50% pokrovnosti cvjetnicama) i guste (51-100%).

Akumulacija sedimenta. Nakon analize video snimaka, svaki transekt je grafički prikazan kao dubinski profil sa različitim vrstama morskog dna što je označeno različitim bojama. Svaki transekt ima tri verzije, za svaku godinu po jednu (2009., 2010., 2011. godina). Preklapanjem i usporedbom transekta dvije uzastopne godine određena je površina akumuliranog ili erodiranog sedimenta na transektu gdje se nalaze morske cvjetnice ili nekompaktno dno. Dubinski profili položeni su na milimetarski papir, određena je površina jednog milimetra te izračunata površina akumuliranog/erodiranog sedimenta što predstavlja bruto akumulaciju sedimenta. Na taj način uspoređeni su transekti 2009. i 2010. godine te 2010. i 2011. godine. Bruto i neto akumulacija sedimenta uspoređena je na različitim stranama uvale (Posedarje strana i prirodna strana).

Bruto akumulacija sedimenta je površina između dijelova dva transekta na kojima se nalaze morske cvjetnice ili nekompaktno dno na kojima se akumulirao sediment. Bruto erozija je površina između dijelova dva transekta na kojima se nalaze morske cvjetnice ili nekompaktno dno na kojima je sediment erodirao. Neto akumulacija sedimenta je razlika između bruto akumuliranog i bruto erodiranog sedimenta i izračunata je za svaki transekt.

Pokrovnost i tipovi morskog dna te gustoća morskih cvjetnica. Postoji nekoliko vrsta pokrovnosti i tipova morskog dna: nekompaktno dno (U-unconsolidated), kamenito (R-rock), alge (A-algae), rijetke morske cvjetnice (SS-sparse seagrass), guste morske cvjetnice (SD-seagrass dense) i školjke (M-mussels). Moguće je bilo zabilježiti četiri vrste promjena u tipovima morskog dna te njegovoj pokrovnosti: iz nekompaktnog u morske cvjetnice i obratno te iz rijetkih morskih cvjetnica u guste i obratno. Promjena se mjerila u metrima kao duljina transekta na kojoj se dogodila promjena.

Bruto promjena iz nekompaktnog dna u dno prekriveno morskim cvjetnicama je promjena u transektu gdje se nekompaktno dno jedne godine promijenilo u dno prekriveno cvjetnicama sljedeće godine. Bruto promjena iz dna prekrivenog morskim cvjetnicama u nekompaktno dno je promjena u transektu gdje se dno prekriveno morskim cvjetnicama jedne godine promijenilo u nekompaktno dno sljedeće godine. Neto promjena iz nekompaktnog dna u dno prekriveno morskim cvjetnicama je razlika između bruto promjene iz nekompaktnog dna u dno prekriveno morskim cvjetnicama i promjene morskog dna prekrivenog morskim cvjetnicama u nekompaktno morsko dno.

Bruto promjena iz gustih cvjetnica u rijetke cvjetnice je promjena u transektu gdje su se guste cvjetnice iz prve godine promijenile u rijetke cvjetnice u sljedećoj godini. Bruto promjena iz rijetkih cvjetnica u guste cvjetnice je promjena u transektu gdje su se rijetke cvjetnice iz prve godine promijenile u guste cvjetnice u sljedećoj godini. Neto promjena iz gustih cvjetnica u rijetke cvjetnice je razlika između bruto promjene iz gustih cvjetnica u rijetke i promjene iz rijetkih cvjetnica u guste.

Bruto i neto promjena iz nekompaktnog dna u dno prekriveno morskim cvjetnicama te promjena u gustoći morskih cvjetnica uspoređene su na različitim stranama uvale (Posedarje strana i prirodna strana).

Uzorkovanje i analiza morskih cvjetnica i sedimenta. Uzorci morskih cvjetnica i sedimenta prikupljeni su na 16 lokacija (osam lokacija na 3 metra dubine i osam lokacija na 4,5 metra dubine) u Novigradskom moru. Lokacije su se nalazile na linijama snimanih transekata.

Uzorkovanje je izvršeno u toplijem periodu kada su morske cvjetnice u svom najrazvijenijem stadiju: 09/2011, 06/2012, 06/2014 i 09/2014. Na svakoj lokaciji prikupljena su tri uzorka morskih cvjetnica korerom promjera 15 cm (Slika 3.3.1.). Deset izdanaka svake vrste u uzorku je upotrijebljeno za daljnje analize. Nakon uzorkovanja, uzorci su isprani te su se razdvojili listovi od rizoma. Određen je broj izdanaka u uzorku te je određena gustoća morskih cvjetnica. Ravnalom je izmjerena je duljina listova, duljina lisne ovojnice te duljina i širina horizontalnog i vertikalnog rizoma s preciznošću 0,5 cm. Nakon morfološke analize uzorci su se sušili 48 sati na 60°C. Nakon sušenja uzorci su izvagani te je izmjerena nadzemna biomasa (biomasa listova) i podzemna biomasa (biomasa rizoma i korijenja) s preciznošću od 0,001 g.

Uzorci sedimenta prikupljeni su pomoću medicinske šprice promjera 3 cm nakon čega su sušeni 48 sati na 60°C. Nakon sušenja, uzorci su poslani u Laboratorij za kemijsku oceanografiju i sedimentologiju gdje je napravljena granulometrijska analiza i određena organska tvar.

Granulometrijska analiza napravljena kako bi se utvrdila veličina i vrsta čestica sedimenta na istraživanom području. Veličina zrna određena je metodom prosijavanja i aerometriranja po Casagrandeu (Strmac, 1952).

Akumulacija sedimenta („zamke za sediment“). Akumulacija sedimenta odredila se upotrebom zamki za sediment tzv. „sediment trapova“ (Slika 3.4.1.). Sediment trap koristi se za hvatanje čestica sedimenta koje se talože u morskom okolišu. Svaki trap sastoji se od 5 epruveta volumena 20,5 mL. Epruvete se postavljaju na međusobnu udaljenost 4 cm (Gacia et al., 1999), na plastičnom štapu duljine 30 cm. Šest trapova postavljeno je na tri metra dubine, a šest na 4,5 metra u 09/2010, 06/2011, 06/2014 i 10/2014.g. Trapovi su postavljeni uz samo dno i izvađeni nakon 15-20 dana. Uzorak prikupljenog sedimenta je filtriran, sušen 24 sata na 60°C te izvagan, nakon čega je određena dnevna stopa akumulacije sedimenta.

Statistička obrada podataka. Statistička analiza izvršena je upotrebom statističkog programa R. Normalnost distribucije testirana je Shapiro-Wilks testom. Za testiranje razlika u prikupljenim uzorcima cvjetnica i sedimenta, razlike u gustoći morskih cvjetnica i pokrovu dna iz videosnimaka korišten je Kruskal-Wallis test, dok je za analizu razlike akumulacije sedimenta korišten parametrijski ANOVA test. Za testiranje korelacije između stope akumulacije sedimenta i gustoće cvjetnica, biomase te duljine lista, internodija i lisne ovojnice korištena je Spearmanova korelacija.

REZULTATI

Podaci o vjetru. Podaci o smjeru i brzini vjetra za razdoblje od lipnja 2009 do lipnja 2011 dobiveni su od Državnog hidrometeorološkog zavoda za postaju najbližu istraživanom području smještenu u Novigradu. Ova meteorološka postaja smještena je otprilike šest kilometara od istraživanom područje te ne odražava u potpunosti uvjete na istraživanom području. Zabilježen je broj dana sa vjetrovima iz smjera sjevera i juga jačine 3 i više prema Beaufort-ovoj skali.

Metoda videografije. Akumulacija i erozija sedimenta. Raspon bruto akumulacije sedimenta po metru transekta u razdoblju od 2009 do 2010 bio je između 0,09 to 206,43 $cm^2\ m^{-1}$ $year^{-1}$ (26,79 ± 47,15), dok je u razdoblju od 2010 do 2011 raspon bio od 52,20 do 35250,00 $cm^2\ m^{-1}$ $year^{-1}$ (16,56 ± 21,82). Razlika između godina i strana uvale nije bila značajna. Ukupna akumulacija sedimenta od 2009-2011 također nije bila značajno različita na različitim stranama uvale. Bruto erozija sedimenta po metru transekta bila je između 0,90 i 55,25 $cm^2\ m^{-1}$ $year^{-1}$ (9,79 ± 15,44) za 2009/2010 godinu, a između 51,84 i 292,51 $cm^2\ m^{-1}$ $year^{-1}$ (29,11 ± 64,75) u 2010/2011 godini. Nije zabilježena značajna razlika na različitim stranama niti godinama. Ukupna bruto erozija sedimenta od 2009 do 2011 po metru transekta također nije bila značajno različita na različitim stranama uvale.

Neto akumulacija sedimenta od 2009 do 2010 bila je 16,99 $cm^2\ m^{-1}$ $year^{-1}$ ± 52,85 i -0,77 $cm^2\ m^{-1}$ $year^{-1}$ u razdoblju od 2010 do 2011. Nije bilo značajne razlike među stranama uvale, iako je veća razina akumulacije zabilježena na strani Posedarja u usporedbi sa prirodnom stranom 2010/2011. Značajna razlika u ukupnoj neto akumulaciji sedimenta na različitim stranama nije zabilježena.

Promjene pokrova dna. Bruto razlika u pokrovnosti dna iz nekompaktnog dna u dno prekriveno morskim cvjetnicama po metru transekta od 2009. do 2010.g. bila je 0,05 ± 0,03 m_{sg}/m_{tr} s rasponom od 0,01 do 0,21 m_{sg}/m_{tr}. Nije zabilježena značajna razlika s obzirom na strane uvale niti godinu. Bruto razlika u pokrovnosti dna iz nekompaktnog dna prekrivenog morskim cvjetnicama u nekompaktno dno značajno je viša na strani Posedarja. Neto razlika između nekompaktnog dna i dna prekrivenog morskim cvjetnicama bila je značajno viša na prirodnoj strani uvale. Usporedba neto razlike između nekompaktnog dna i dna prekrivenog morskim cvjetnicama po godinama pokazala je da se 2009/2010 g. sediment akumulirao dok je 2010/2011 erodirao.

Bruto razlika gustoće cvjetnica iz rijetkih u guste morske cvjetnice po metro transekta iznosila je 0,04 m_{sg}/m_{tr} ± 0,04 u razdoblju 2009/2010 s rasponom između 0,01 do 0,16 m_{sg}/m_{tr}, dok je 2010/2011 srednja vrijednost bila 0,06 m_{sg}/m_{tr} ± 0,07 s rasponom između 0,01 do 0,27. nije zabilježena značajna razlika na različitim stranama uvale niti među godinama. Srednja vrijednost suprotne promjene, iz gustih morskih cvjetnica u rijetke, u 2009/2010 g. bila je 0,05 m_{sg}/m_{tr} ± 0,08 s rasponom od 0,01 do 0,31 m_{sg}/m_{tr}, a 2010/2011 g. 0,04 m_{sg}/m_{tr} ± 0.05 s rasponom od 0,02 do 0,16 m_{sg}/m_{tr}. Značajna promjena iz gustih u rijetke cvjetnice zabilježena je na strani Posedarja. Neto razlika u gustoći cvjetnica 2009/2010 iznosila je -0,01 ± 0,09 s rasponom od -0,27 do 0,15 i negativne vrijednosti su pokazatelj gubitka gustih morskih cvjetnica. U razdoblju 2010/2011 bila je 0,02 ± 0,08 s rasponom od -0,14 do 0,22 m_{dsg}/m_{tr}. Ukupna neto razlika gustoće bila je manja u uvjetima akumulacije sedimenta što upućuje na smanjenje gustoće cvjetnica u uvjetima taloženja sedimenta.

Morfologija morskih cvjetnica i biomasa. Uzorci su prikupljeni iz mješovitog naselja morskih cvjetnica koje se sastoji od tri vrste: *Zostera noltei*, *Zostera marina* i *Cymodocea nodosa*. Srednja gustoća bila je 1405 ± 852 izdanaka/m^2. Veća gustoća zabilježena je na prirodnoj strani uvale (1627 izdanaka/m^2) dok je na strani Posedarja iznosila 1171 izdanaka/m^2. Gustoća je bila veća i na 3 metra dubine, a iznosila je 1793 izdanaka/m^2. Srednja vrijednost nadzemne biomase bila je 44,0 ± 27,2 gdw/m^2. Značajno veća nadzemna biomasa zabilježena je na prirodnoj strani, ali nije bilo razlike među dubinama. Srednja vrijednost podzemne biomase bila je 126,4 ± 74,6 gdw/m^2 i nije zabilježena značajna razlika po stranama, ali je na 4,5 metra dubine bila značajno veća podzemna biomasa.

Biomasa, gustoća i morfološke osobine vrste *Zostera noltei*. Izmjerena vrijednost nadzemne biomase bila je 26,5 ± 21,4 gdw/m^2 i bila je značajno viša na prirodnoj strani uvale i na dubini 3 metra. Korelacija između nadzemne biomase i stope akumulacije sedimenta nije nađena. Srednja vrijednost podzemne biomase bila je 48,1 ± 36,1 gdw/m^2 te je bila značajno viša na prirodnoj strani i na 3 metra dubine. Korelacija između podzemne biomase i stope akumulacije sedimenta nije nađena.

Izmjerena gustoća bila je 1382 ± 936 izdanaka/m^2 te je bila značajno viša na prirodnoj strani i na 3 metra dubine. Korelacija između gustoće i stope akumulacije sedimenta nije nađena. Duljina lista iznosila je 21,1 ± 9,4 cm i nije se značajno razlikovala na različitim stranama niti dubinama. Korelacija između duljine lista i stope akumulacije sedimenta nije nađena. Duljina lisne ovojnice bila je 3,4 ± 2,1 cm i također nije bilo razlike među stranama ni dubinama. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Duljina horizontalnog internodija bila je 1,3 ± 0,7 cm. Nije zabilježena značajna razlika između strana, a duljina je bila nešto veća na 3 metra dubine. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Zabilježeni su vertikalni internodiji vrste *Z. noltei* prvi put u Jadranskom i Mediteranskom moru. Duljina vertikalnog internodija bila je 0,3 ± 0,2 cm što je značajno kraće u usporedbi sa duljinom horizontalnog rizoma čija je srednja duljina 1,3 cm. Vertikalni internodiji bili su značajno dulji na prirodnoj strani i tri metra dubine. Zabilježena je pozitivna korelacija između duljine vertikalnog internodija i stope akumulacije sedimenta. Uzorak s najviše zabilježenih vertikalnih rizoma zabilježen je na prirodnoj strani uvale. Zabilježena je i pozitivna korelacija između broja vertikalnih rizoma i stope akumulacije sedimenta.

Biomasa, gustoća i morfološke osobine vrste *Zostera marina*. Izmjerena vrijednost nadzemne biomase bila je 14,8 ± 15,5 gdw/m^2 i bila je značajno viša na prirodnoj strani uvale dok razlika po dubini nije zabilježena. Zabilježena je pozitivna korelacija između nadzemne biomase i stope akumulacije sedimenta. Srednja vrijednost podzemne biomase bila je 40,9 ± 36,4 gdw/m^2 te je bila značajno viša na prirodnoj strani dok razlika po dubini nije zabilježena. Korelacija između podzemne biomase i stope akumulacije sedimenta nije nađena.

Izmjerena gustoća bila je 248 ± 225 izdanaka/m^2 te je bila značajno viša na prirodnoj strani dok razlika po dubini nije zabilježena. Slaba pozitivna korelacija između gustoće i stope akumulacije sedimenta je zabilježena. Duljina lista iznosila je 18,1 ± 8,1 cm i bila je značajno veća na strani Posedarje, ali razlika nije zabilježena po dubinama. Korelacija između duljine lista i stope akumulacije sedimenta nije nađena. Duljina lisne ovojnice bila je 3,7 ± 1,8 cm i također je bila dulja na strani Posedarja dok po dubinama nije bilo razlike. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Duljina horizontalnog internodija bila je 1,0 ± 0,4 cm i bila je značajno veća na strani Posedarje i tri metra dubine. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Zabilježeni su vertikalni internodiji vrste *Z. marina* prvi put prema postojećoj literaturi. Duljina vertikalnog internodija bila je 0,4 ± 0,2 cm i značajno je manja od duljine horizontalnog rizoma. Nije zabilježena razlika u duljini vertikalnog internodija na različitim stranama ni dubinama. Nije zabilježena korelacija između duljine vertikalnog internodija i stope akumulacije sedimenta.

Biomasa, gustoća i morfološke osobine vrste *Cymodocea nodosa*. Izmjerena vrijednost nadzemne biomase bila je 35,5 ± 28,0 gdw/m^2. Nije zabilježena značajna razlika nadzemne biomase na različitim stranama ni dubinama. Nije zabilježena korelacija između nadzemne biomase i stope akumulacije sedimenta. Srednja vrijednost podzemne biomase bila je 132,1 ±

75,3 gdw/m^2 te je bila značajno viša na strani Posedarja dok razlika po dubini nije zabilježena. Korelacija između podzemne biomase i stope akumulacije sedimenta nije nađena.

Izmjerena gustoća bila je 775 ± 484 izdanaka/m^2. Nije zabilježena značajna razlika gustoće na različitim stranama ni dubinama. Korelacija između gustoće i stope akumulacije sedimenta nije nađena.

Duljina lista iznosila je 21,0 ± 10,0 cm. Nije zabilježena značajna razlika duljine lista na različitim stranama dok je duljina bila veća na tri metra dubine. Nije zabilježena korelacija između duljine lista i stope akumulacije sedimenta. Duljina lisne ovojnice bila je 3,9 ± 2,0 cm i nije bilo razlike na stranama dok je na tri metra dubine bila dulja nego na 4,5 metra dubine. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Duljina horizontalnog internodija bila je 2,6 ± 2,0 cm i bila je značajno veća na prirodnoj strani i 4.5 metra dubine. Nije zabilježena korelacija sa stopom akumulacije sedimenta. Duljina vertikalnog rizoma bila je 2,4 ± 1,4 cm i značajno je veća na strani Posedarja, ali po dubinama nije zabilježena razlika. Nije zabilježena korelacija sa stopom akumulacije sedimenta.

Zamke za sediment i uzorci sedimenta.

Stopa akumulacije sedimenta. Stopa akumulacije sedimenta bila je 65,1 ± 30,6 gdw/m^{2}day i bila je značajno veća na prirodnoj strani, ali nije zabilježena razlika po dubinama.

Sadržaj organske tvari i granulometrijska analiza uzoraka sedimenta. Sadržaj organske tvari u uzorcima sedimenta bio je 3,3 ± 2,2 % i bio je značajno veći na strani Posedarje dok razlika po dubinama nije zabilježena.

Udio gline u uzorcima bio je 18,87 ± 9,82 % i bio je značajno veći na strani Posedarja, a razlika po dubini nije zabilježena. Udio gline je negativno koreliran sa stopom akumulacije sedimenta. Udio silta bio je 22,03 ± 22,49 % i bio je značajno veći na strani Posedarje dok razlika po dubinama nije zabilježena. Udio gline je negativno koreliran sa stopom akumulacije sedimenta. Udio pijeska bio je 52,82 ± 26,56 % i bio je značajno veći na prirodnoj strani, a nije bilo razlike po dubinama. Zabilježena je pozitivna korelacija sa stopom akumulacije sedimenta. Udio šljunka bio je 6,29 ± 7,10 % i nije bilo razlike na različitim stranama ni dubinama i nije zabilježena značajna korelacija sa stopom akumulacije sedimenta.

ZAKLJUČCI

Ova disertacija doprinosi boljem razumijevanju stanja mješovitog naselja morskih cvjetnica u zapadnom dijelu Novigradskog mora u istočnom Jadranu pri raznim uvjetima sedimentacije. Metoda videografije pokazala se uspješnom metodom za otkrivanje neto akumulacije sedimenta i otkrivanje promjena u gustoći morskih cvjetnica te vrsti pokrova na morskom dnu. Nadalje, ovo istraživanje otkrilo je nove i rijetke morfološke osobine morskih cvjetnica roda *Zostera*. Istraživano područje je Natura 2000 područje te će podaci prikupljeni ovim istraživanjem doprinijeti i pomoći boljem upravljanju, zaštiti i praćenju naselja morskih cvjetnica u Novigradskom moru te će se moći uočiti novonastale promjene uslijed antropogenog djelovanja, klimatskih promjena i ostalih prirodnih poremećaja.

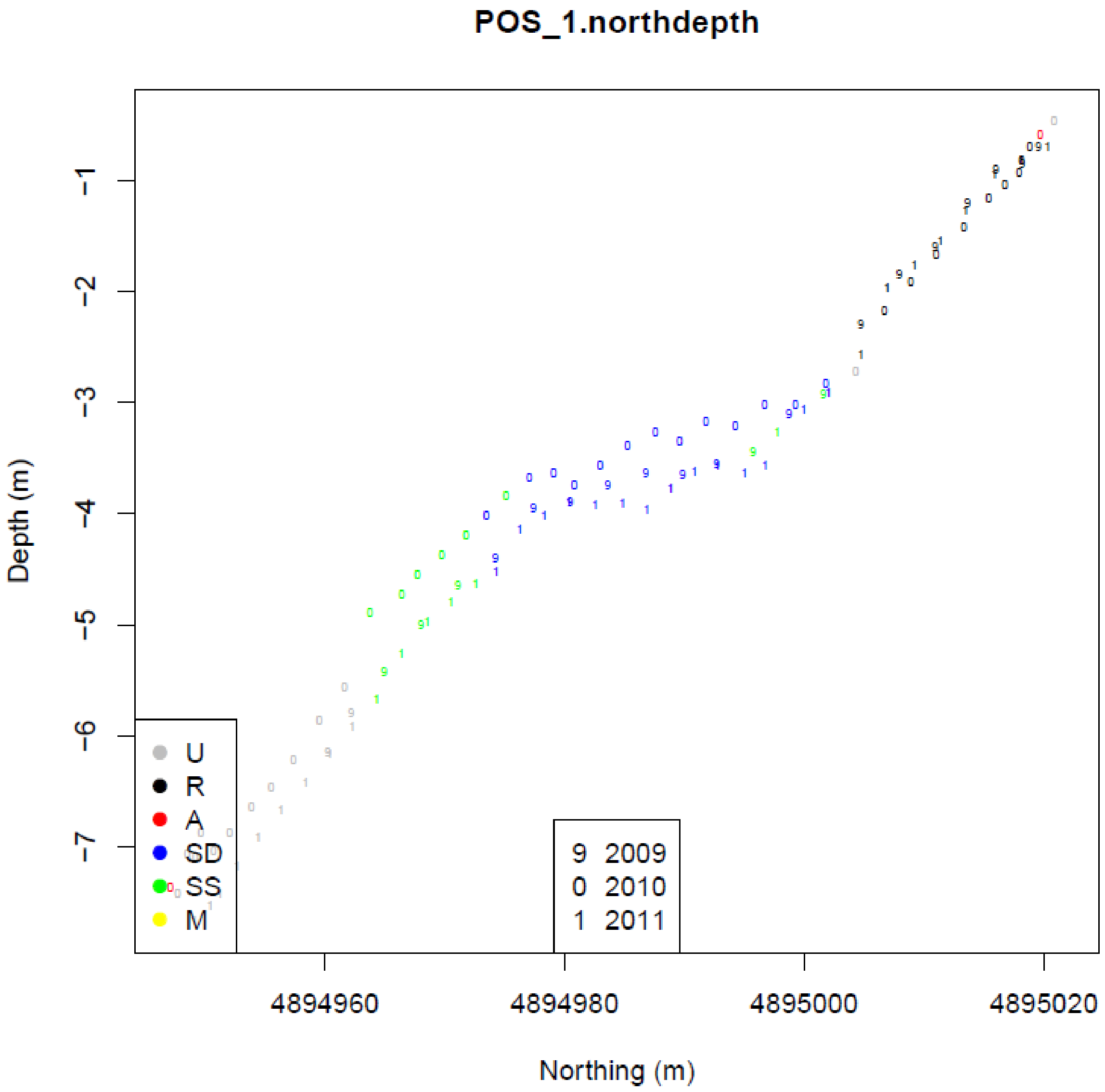
Provedenim istraživanjem došlo se do sljedećih zaključaka:

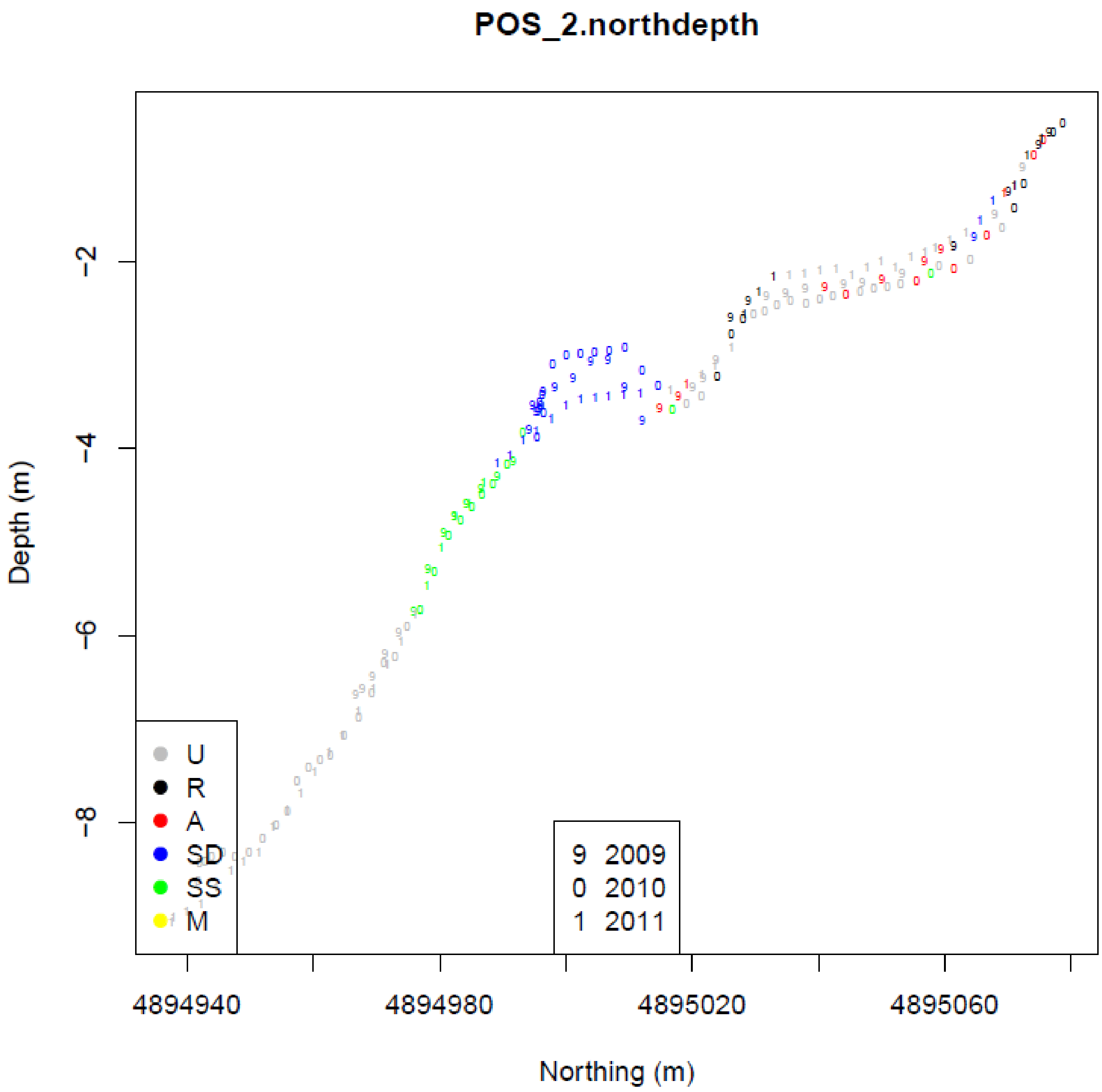
- metoda videografije korištena u ovom istraživanju uspješno je zabilježila neto premještanje sedimenta tj. akumulaciju i eroziju, osim toga zabilježene su i promjene u gustoći naselja morskih cvjetnica kao i promjene u pokrovu morskog dna u razdoblju 2009/2010 i 2010/2011 godine,
- premještanje sedimenta djelomično uzrokuje promjene u rasprostranjenosti morskih cvjetnica na istraživanom područje,
- nadzemna biomasa prikupljenih uzoraka morskih cvjetnica bila je viša na području sa većom stopom akumulacije sedimenta te je moguće da stopa akumulacije sedimenta nije bila previše visoka što nije uzrokovalo smrtnost morskih cvjetnica te su se one mogle prilagoditi na postojeće uvjete,
- uzorci morskih cvjetnica prikupljeni na području sa većom stopom akumulacije sedimenta imali su veću podzemnu biomasu što upućuje na razvoj većeg "sustava sidrenja" ("anchoring system") kojim se cvjetnice pričvršćuju za dno kako bi se bolje nosile sa jačim morskim strujama što je u skladu sa opažanjima iz literature (Wicks et al. 2009),
- veća biomasa vrste *Zostera noltei* na tri metra dubine je vjerojatno uzrokovana boljim uvjetima osvjetljenja nego što su na 4,5 metra, a 4,5 metra je i dubina donje granice rasprostranjenosti ove vrste na istraživanom području,

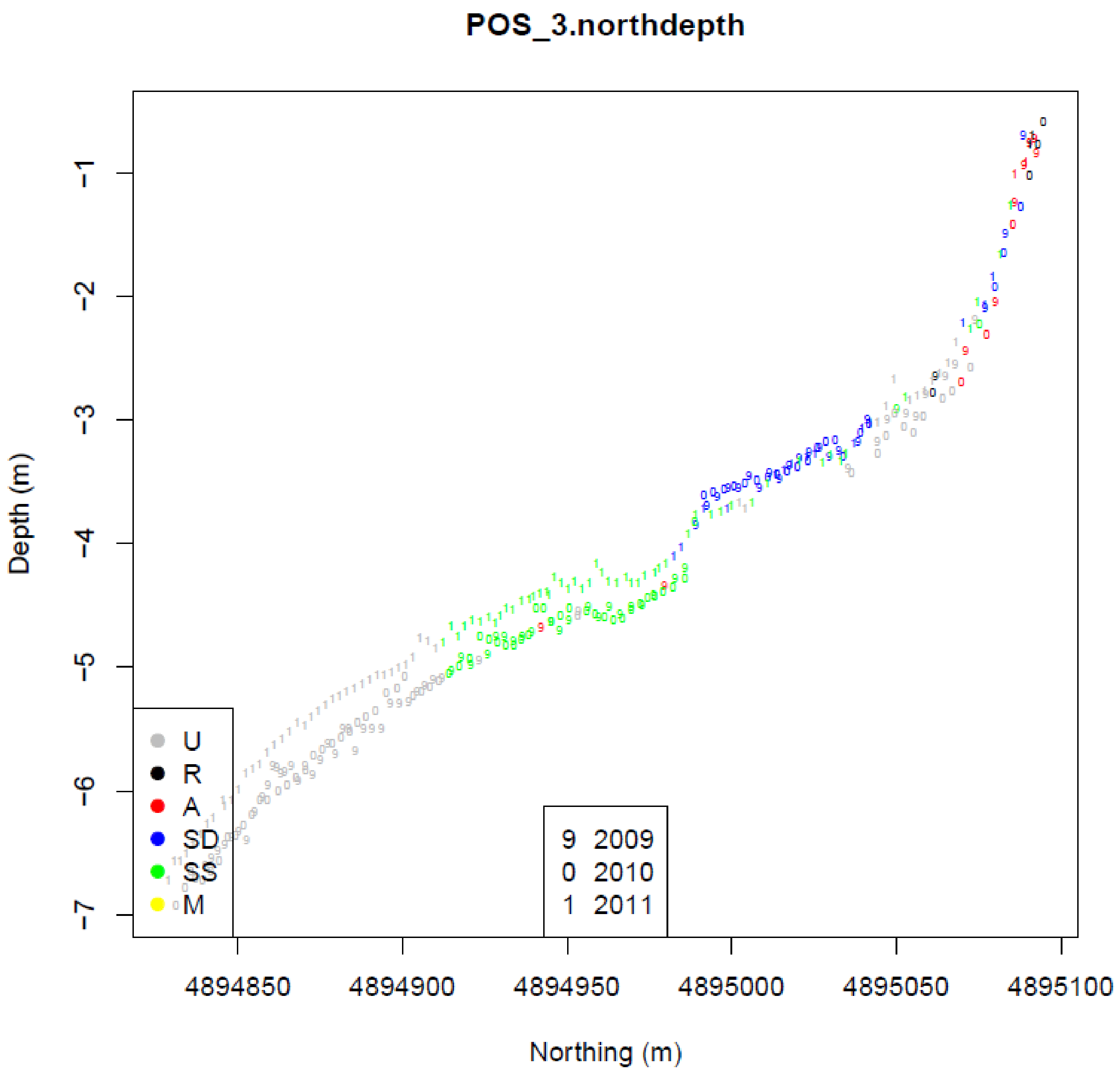
- kod vrste *Zostera noltei* nisu zabilježene razlike u duljini lista i lisne ovojnice s obzirom na stopu akumulacije sedimenta što odgovara provedenom istraživanju autora Cabaço i Santos (2007),
- značajno duži listovi i lisna ovojnica vrste *Zostera marina* zabilježeni su u području s većim udjelom organske tvari te većeg udjela silta i gline što može biti posljedica niskog sadržaja kisika u takvim sedimentima. Navedeno je u skladu sa podacima iz literature (Koch 2001) prema kojima dolazi do povećanja lisne površine kao odgovor na smanjenu koncentraciju kisika u sedimentu,
- vertikalni rizom pronađen kod vrsta *Zostera marina* i *Zostera noltei* je vjerojatno induciran zatrpavanjem sedimentom uzrokovanim sjevernim i sjeveroistočnim vjetrovima, a ova morfološka osobina može se tumačiti kao lokalna adaptacija istraživane populacije morskih cvjetnica na zatrpavanje sedimentom,
- *Cymodocea nodosa* nije pokazala tipične posljedice zatrpavanja sedimentom kao što su produženi vertikalni rizom, smanjenje duljine lista, povećanje lisne ovojnice ili smanjenje biomase u odnosu na stopu akumulacije sedimenta što upućuje na to da neki drugi faktori kontroliraju ovu vrstu morske cvjetnice na istraživanom području.

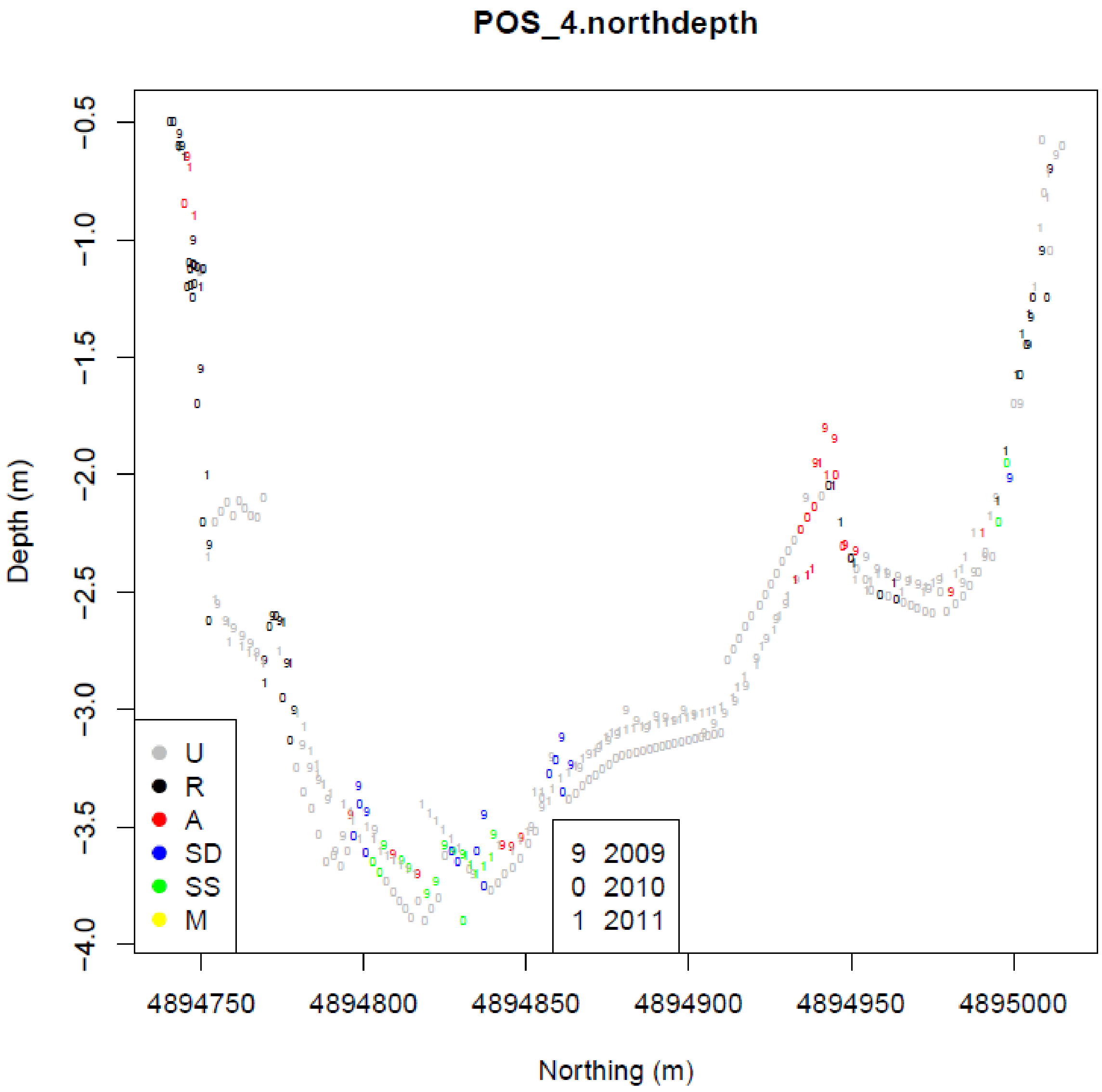
9. APPENDICES

Appendix I. Transect depth profiles of the monitored transects from 2009, 2010 and 2011.




POS_2.northdepth
Depth (m)
-2
-4
-6
-8
Northing (m)
4894940
4894980
4895020
4895060
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


POS_3.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
-7
Northing (m)
4894850
4894900
4894950
4895000
4895050
4895100
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


POS_4.northdepth
Depth (m)
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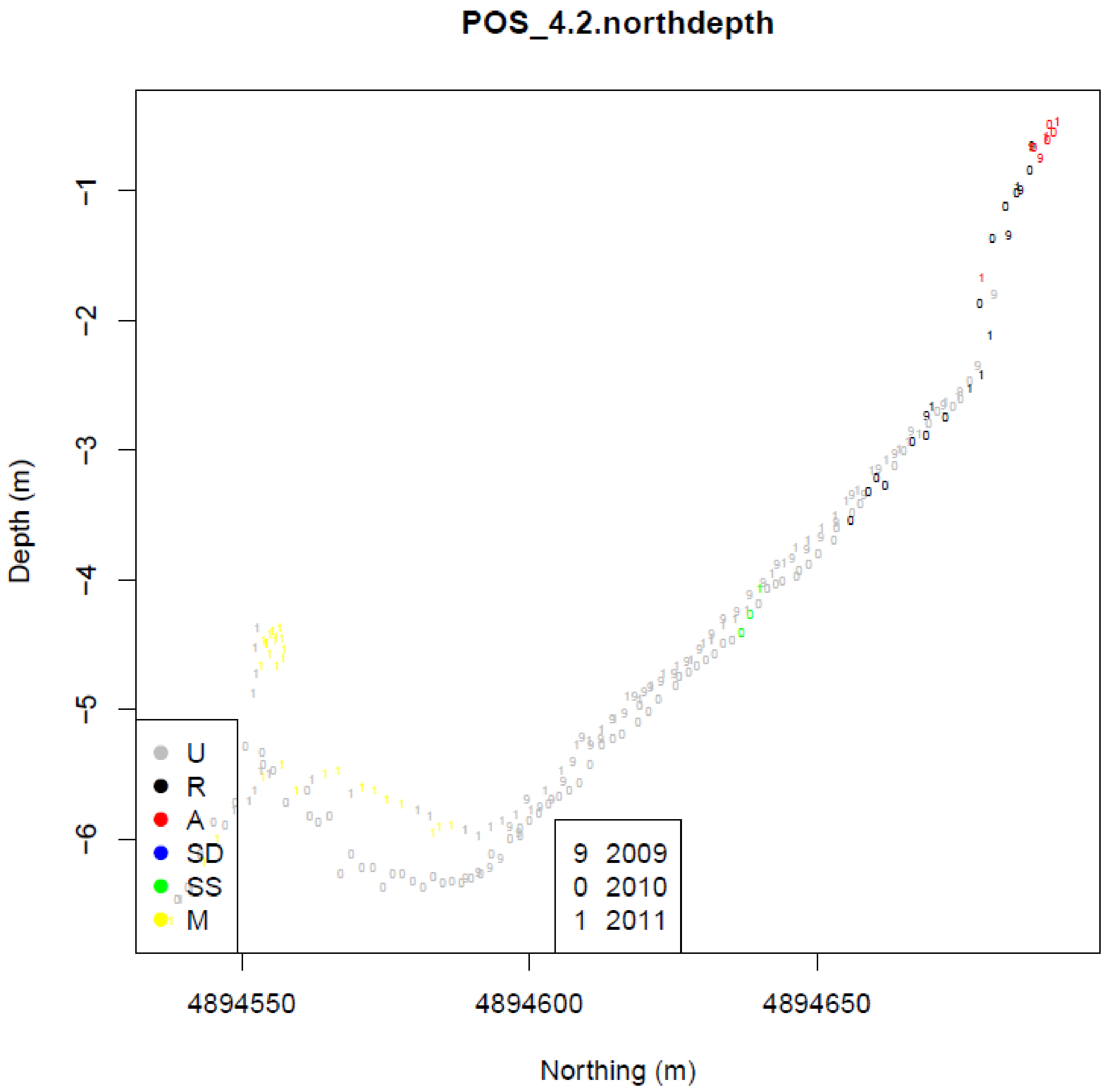
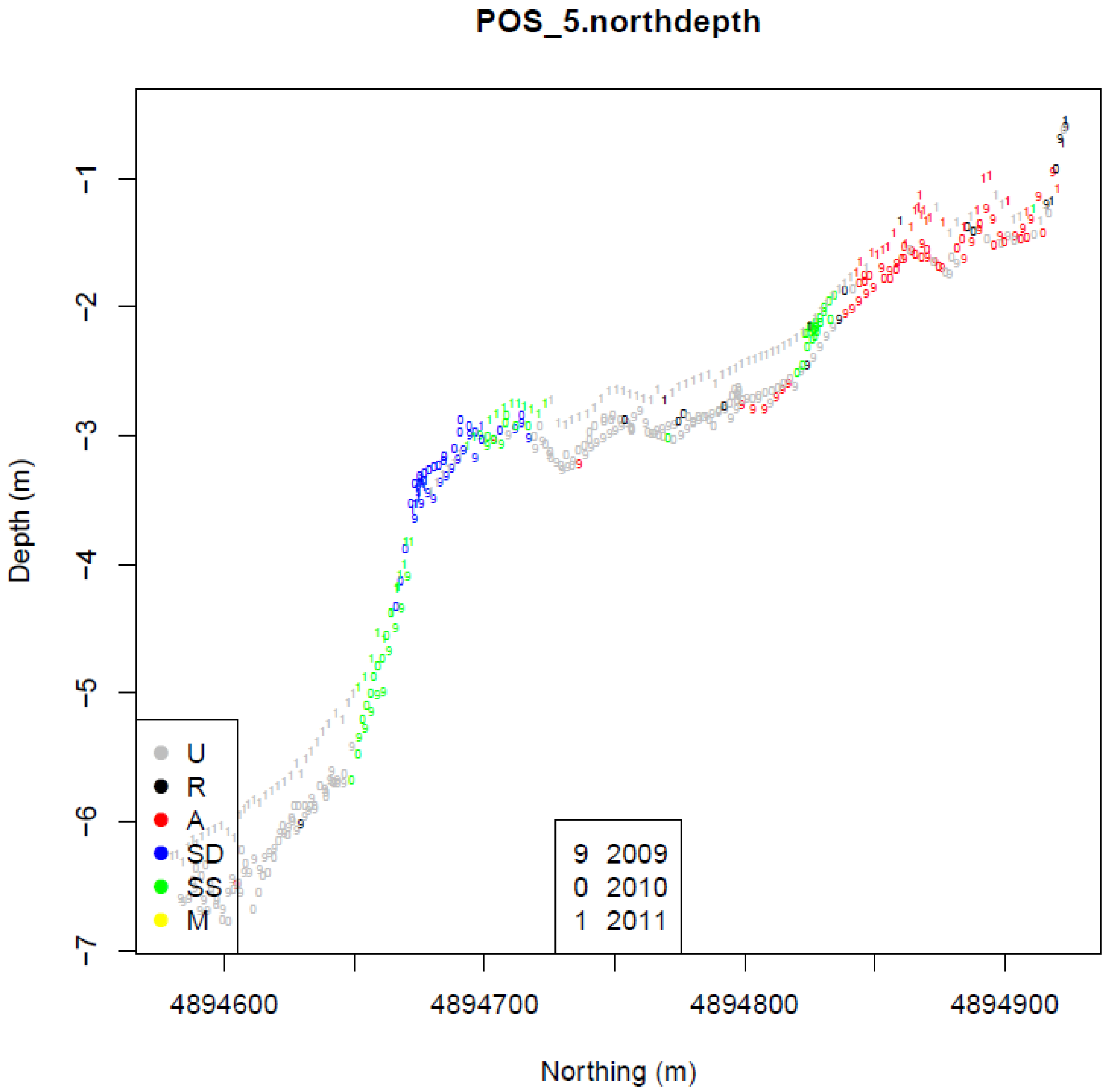
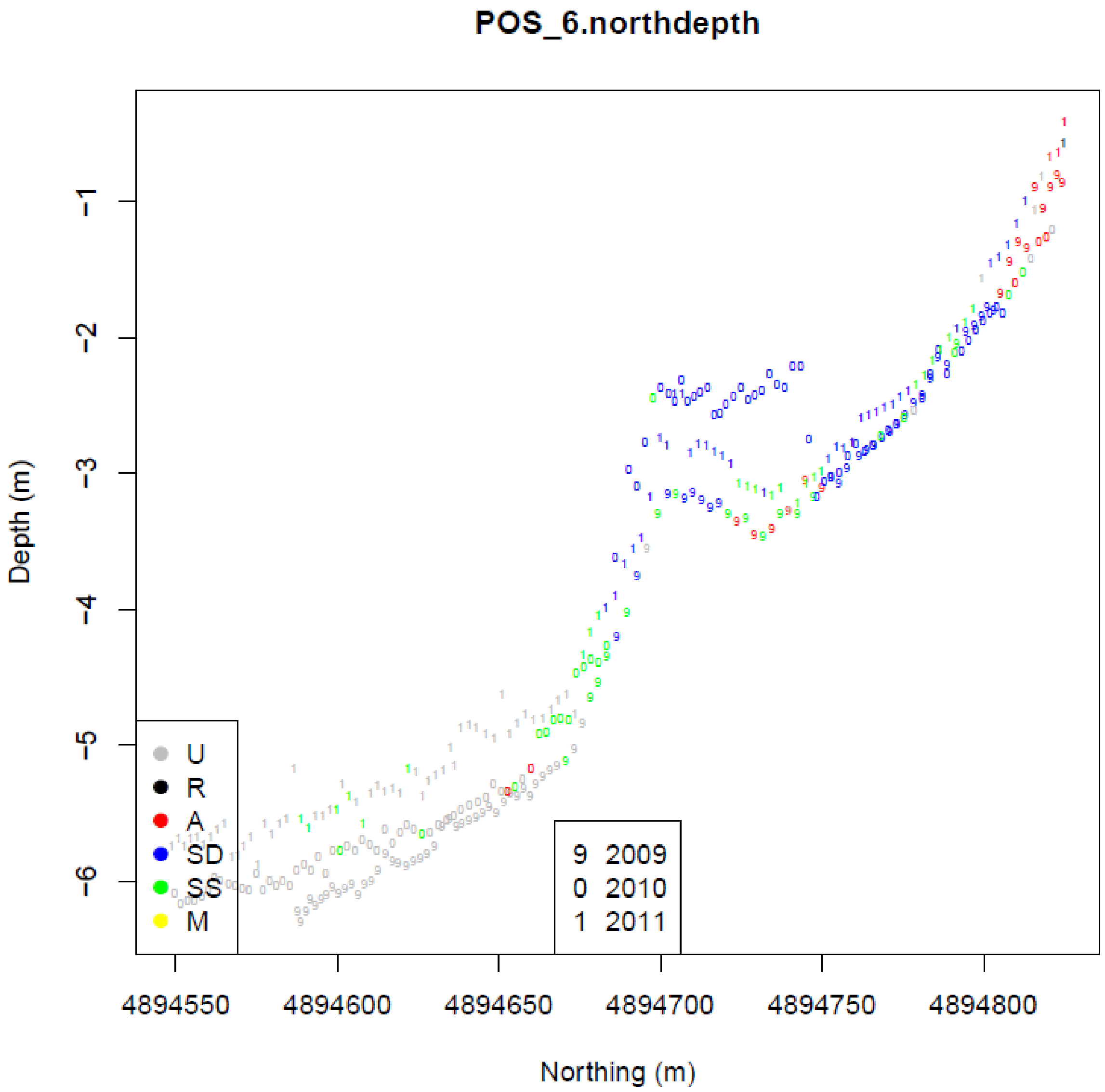
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
4894750
4894800
4894850
4894900
4894950
4895000
Northing (m)
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


POS_4.2.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4894550
4894600
4894650
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


POS_5.northdepth
Depth (m)
−1
−2
−3
−4
−5
−6
−7
Northing (m)
4894600
4894700
4894800
4894900
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


POS_6.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
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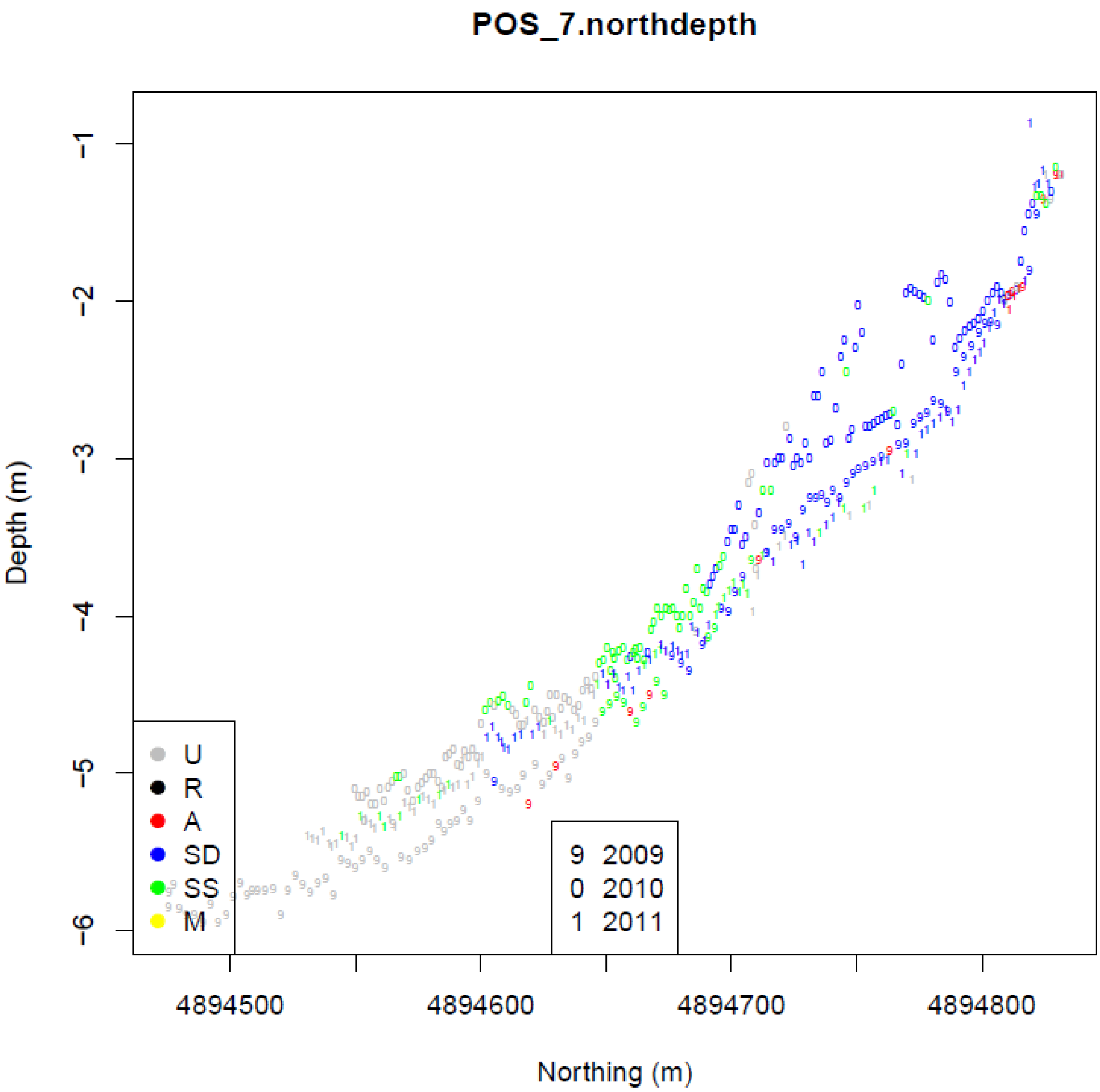
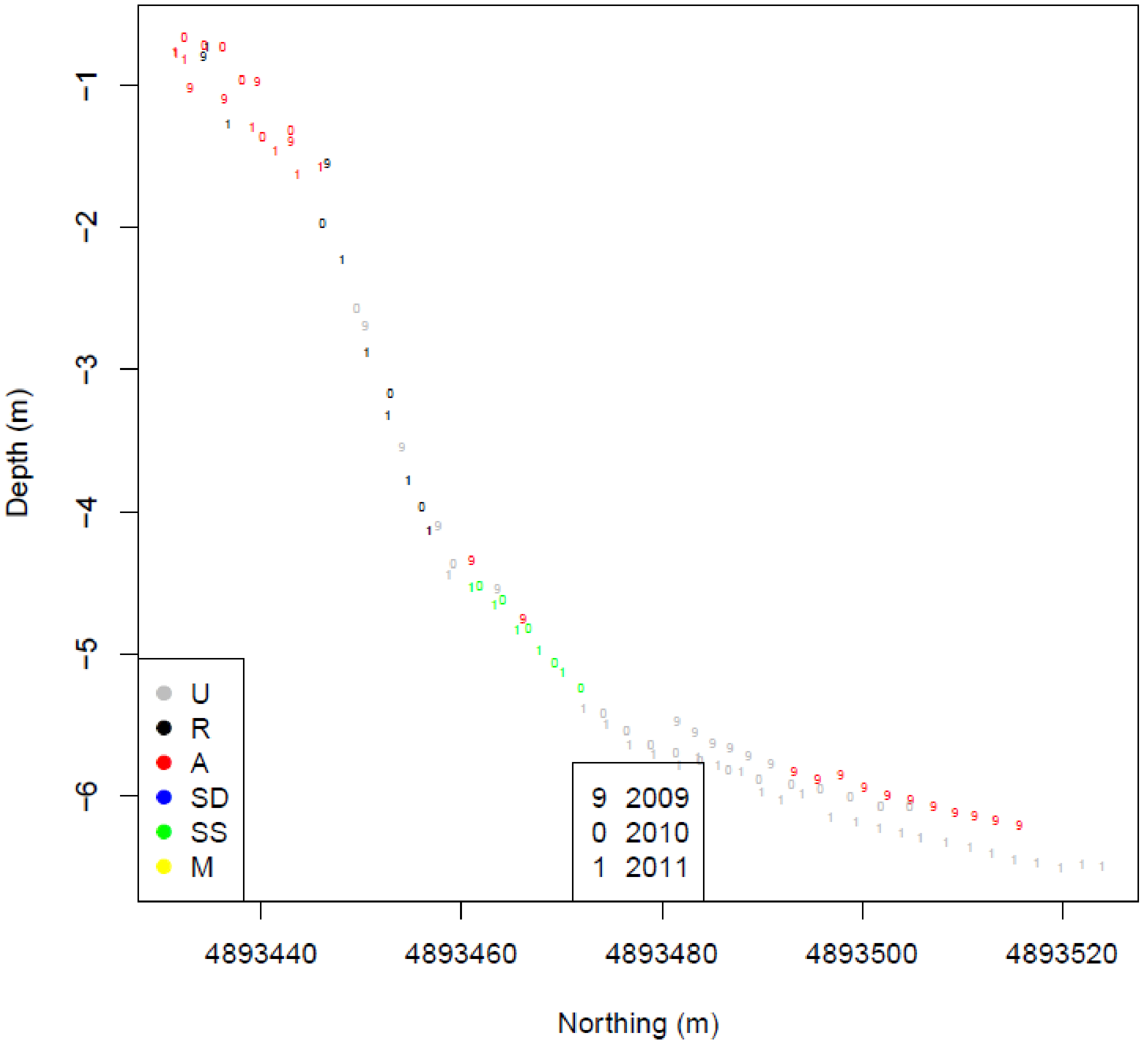
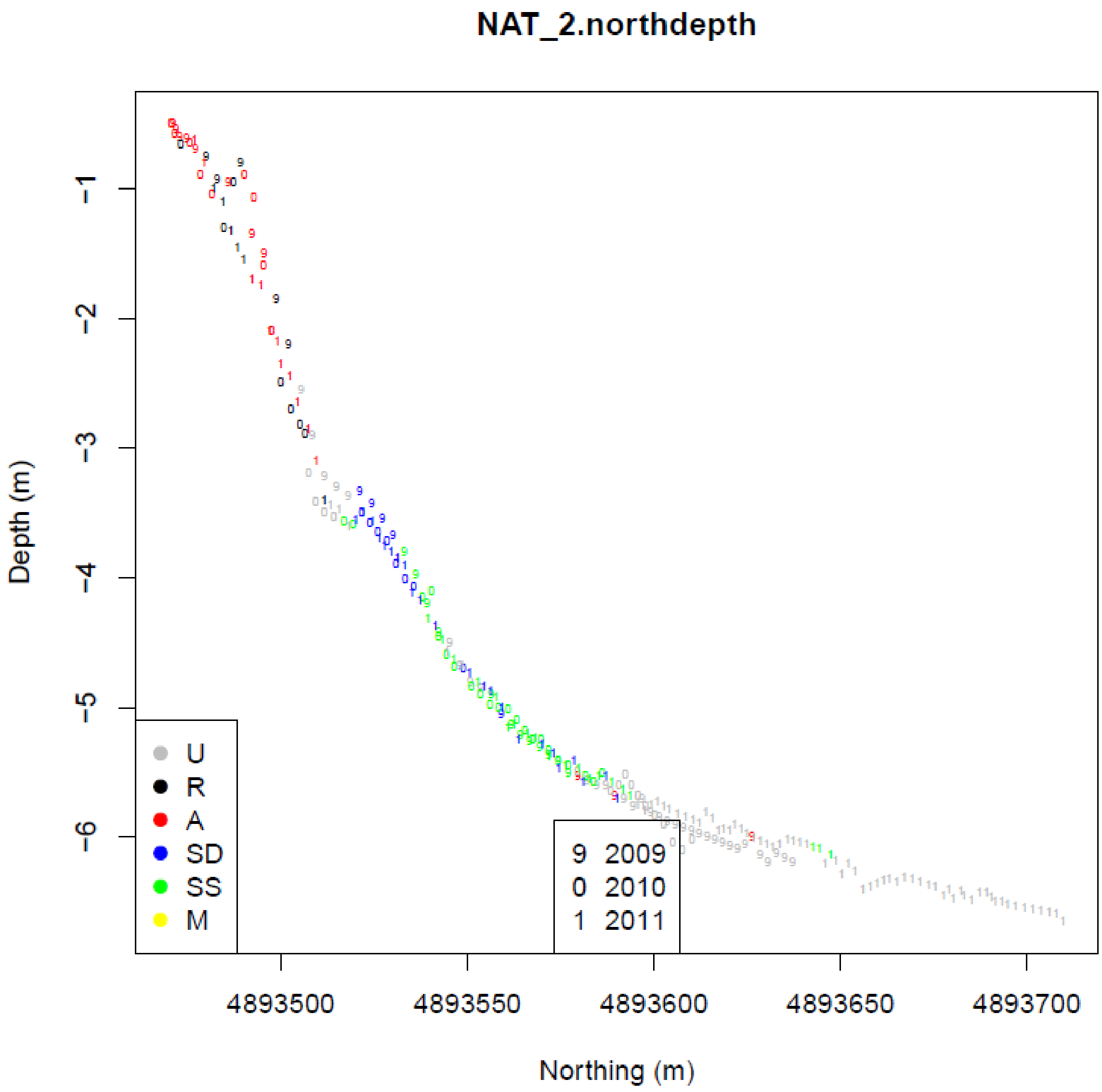
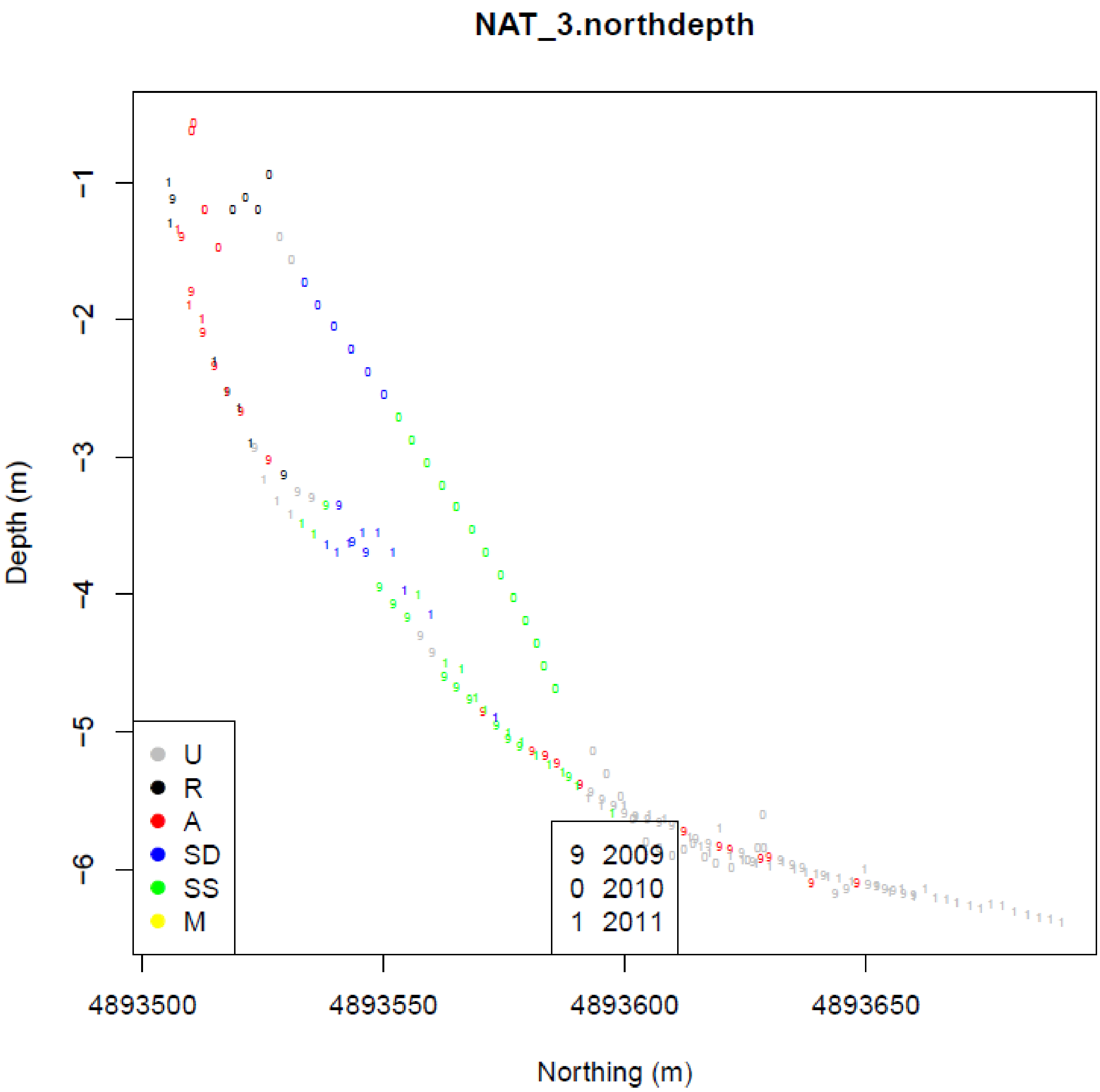
4894600
4894650
4894700
4894750
4894800
U
R
A
SD
SS
M
9 2009
0 2010
1 2011

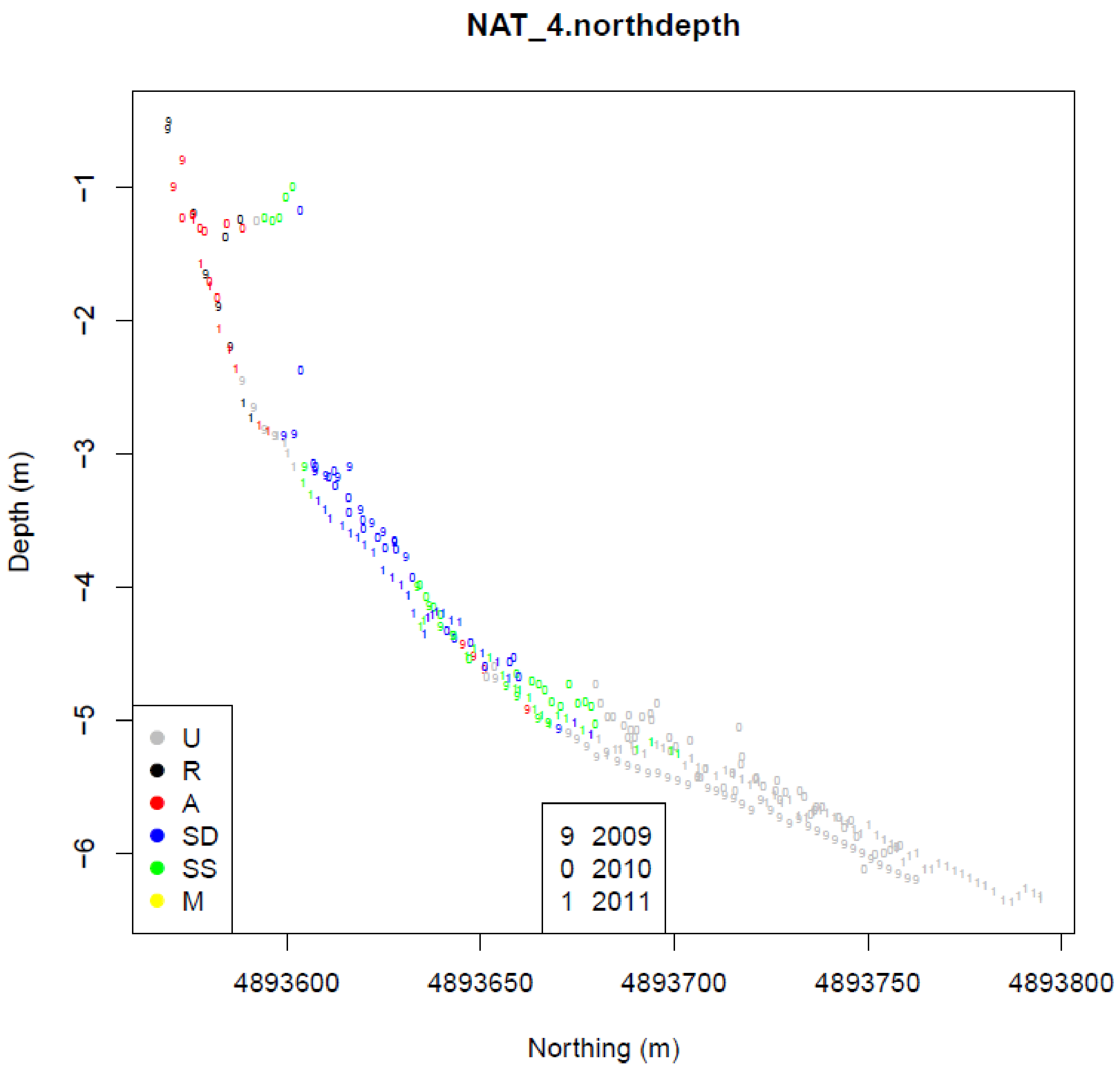

POS_7.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4894500
4894600
4894700
4894800
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011

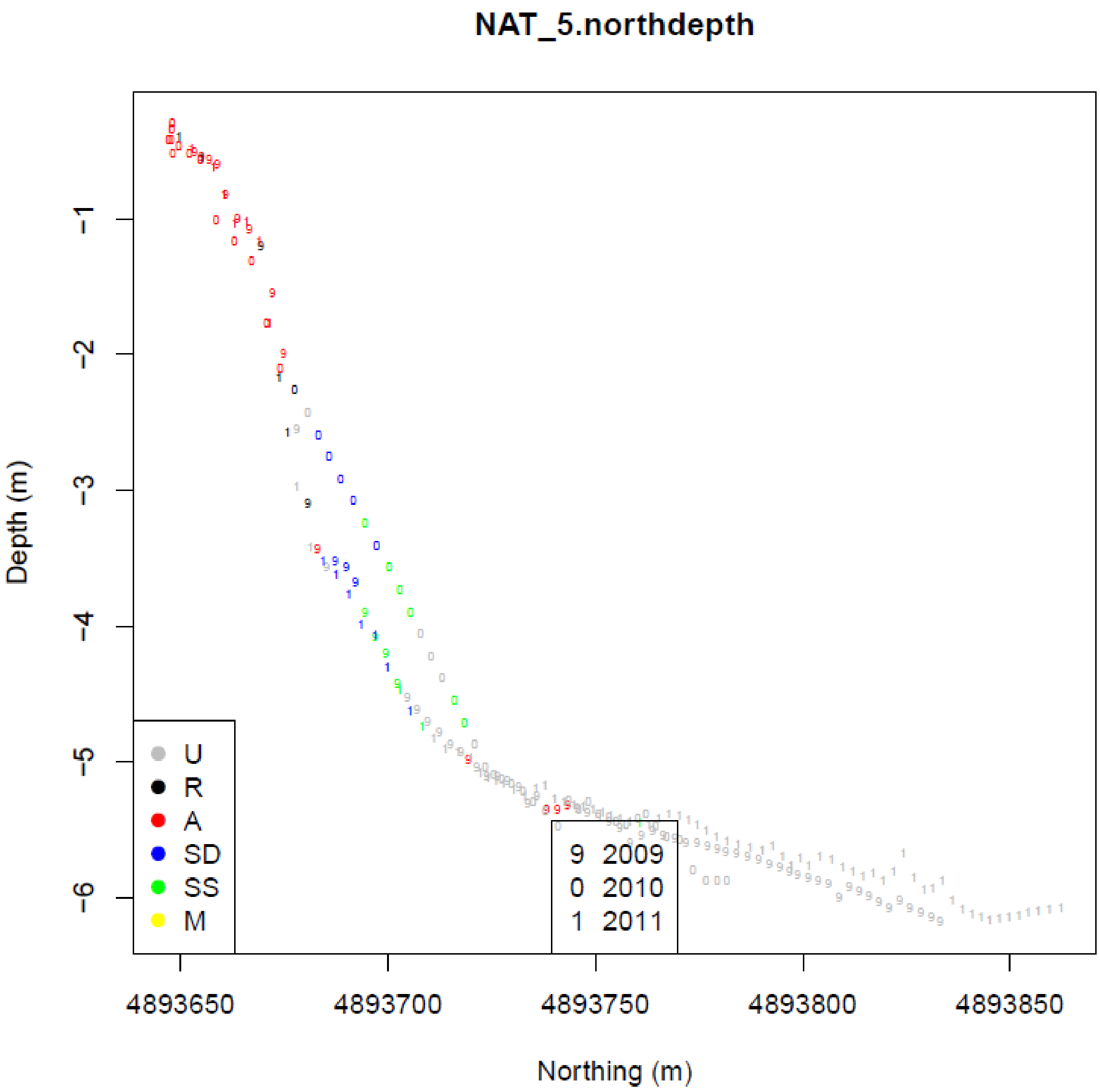
NAT_1.northdepth

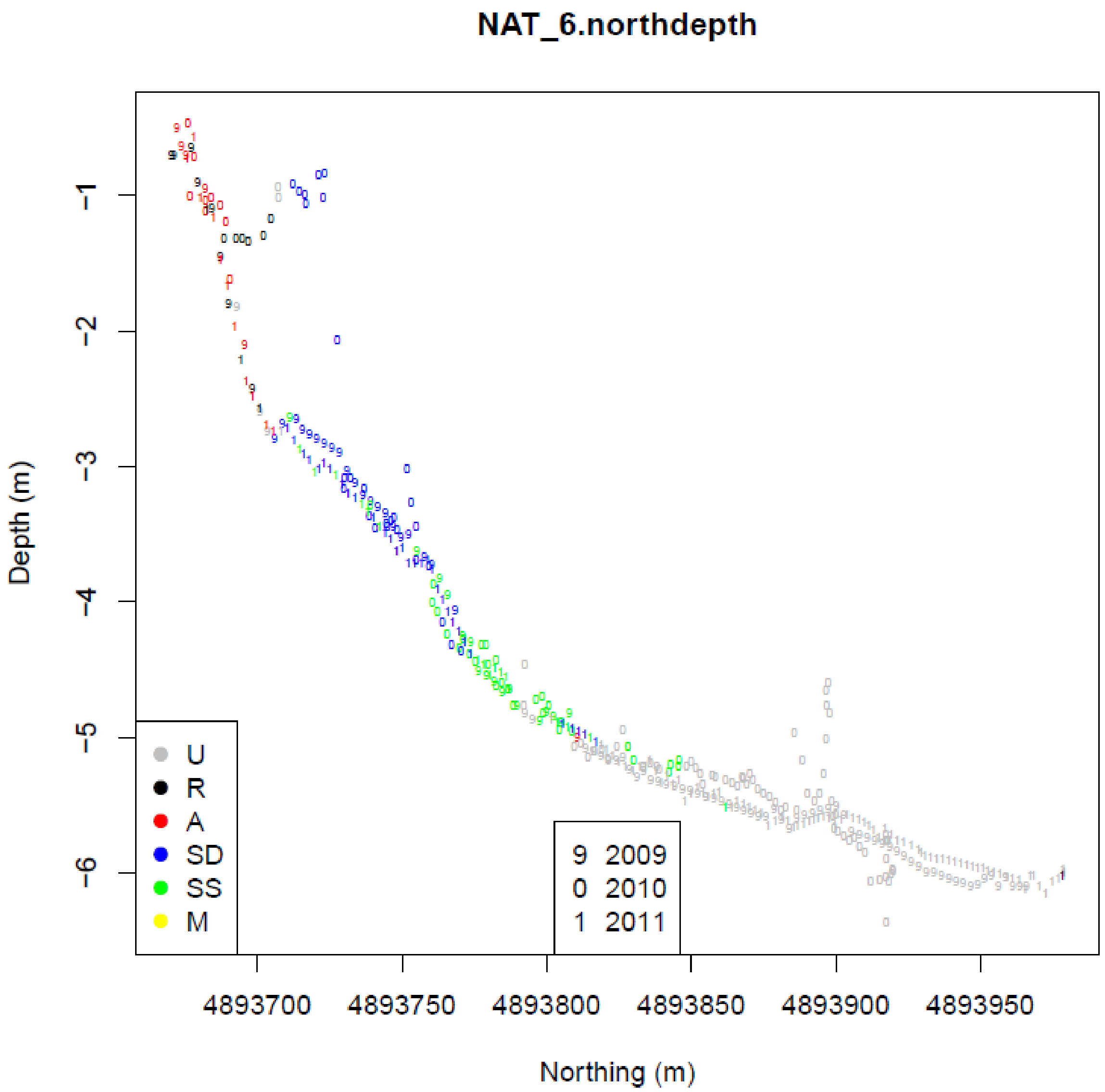


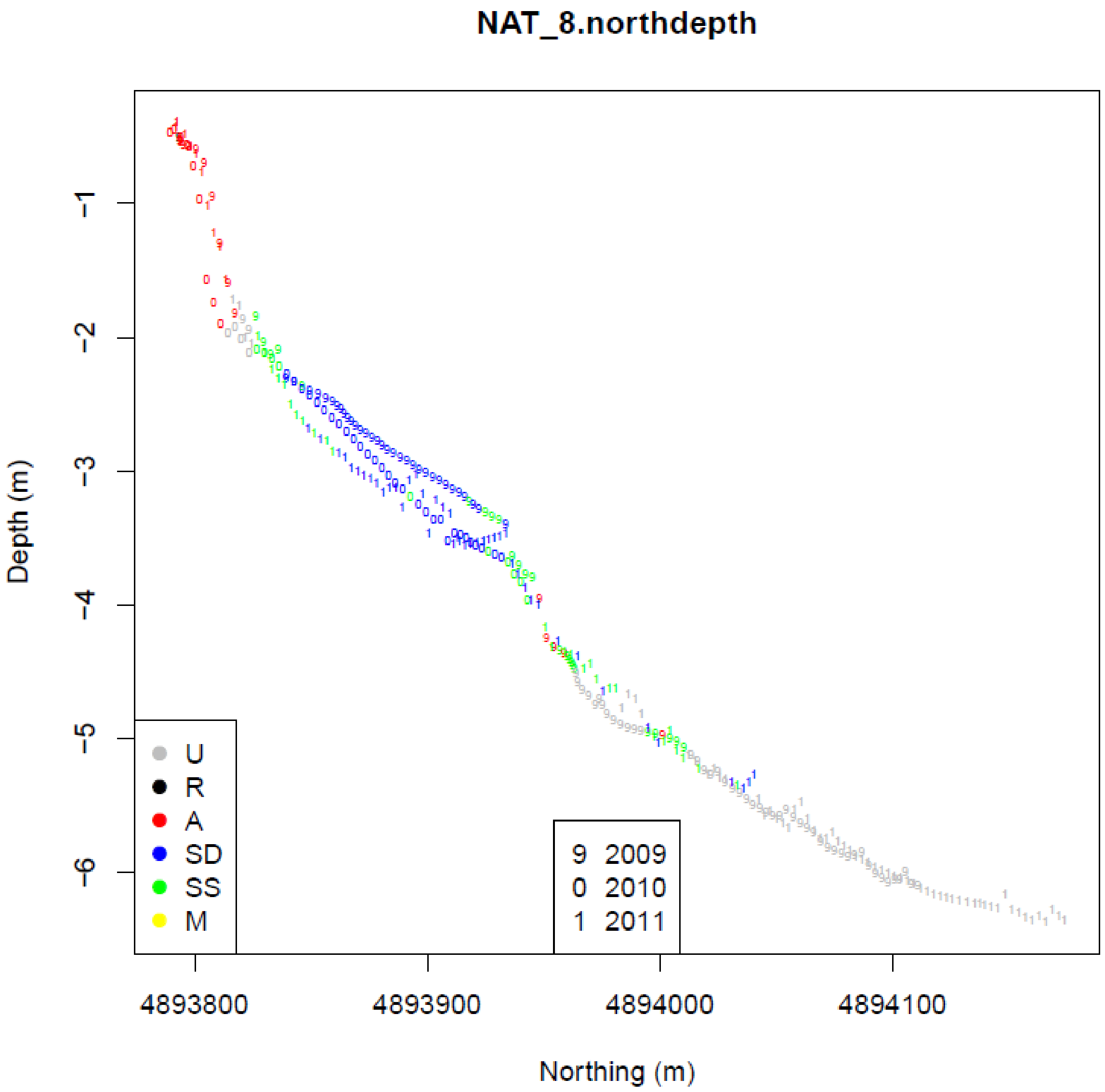

NAT_2.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4893500
4893550
4893600
4893650
4893700
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011

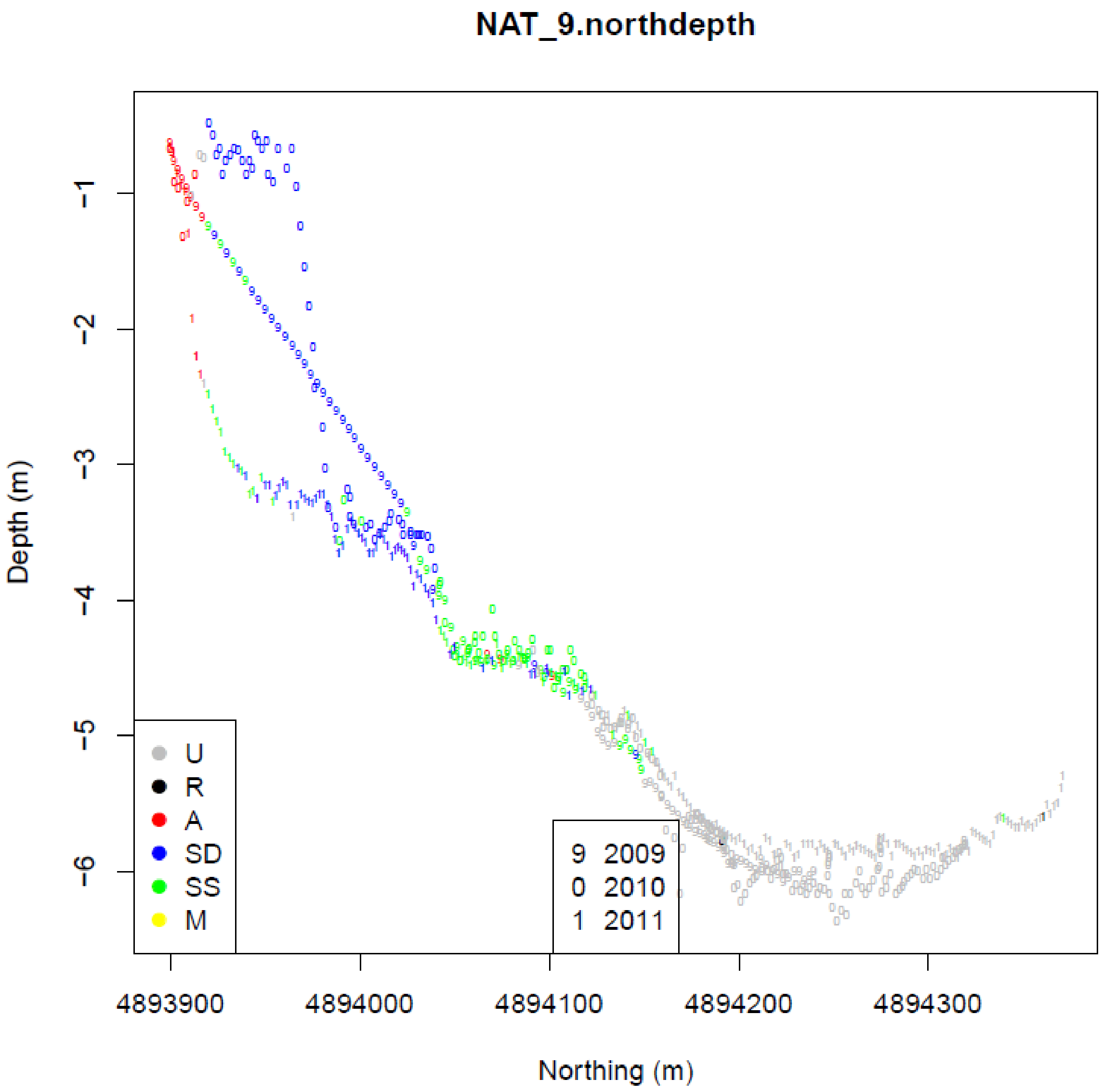

NAT_3.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4893500
4893550
4893600
4893650
U
R
A
SD
SS
M
9 2009
0 2010
1 2011

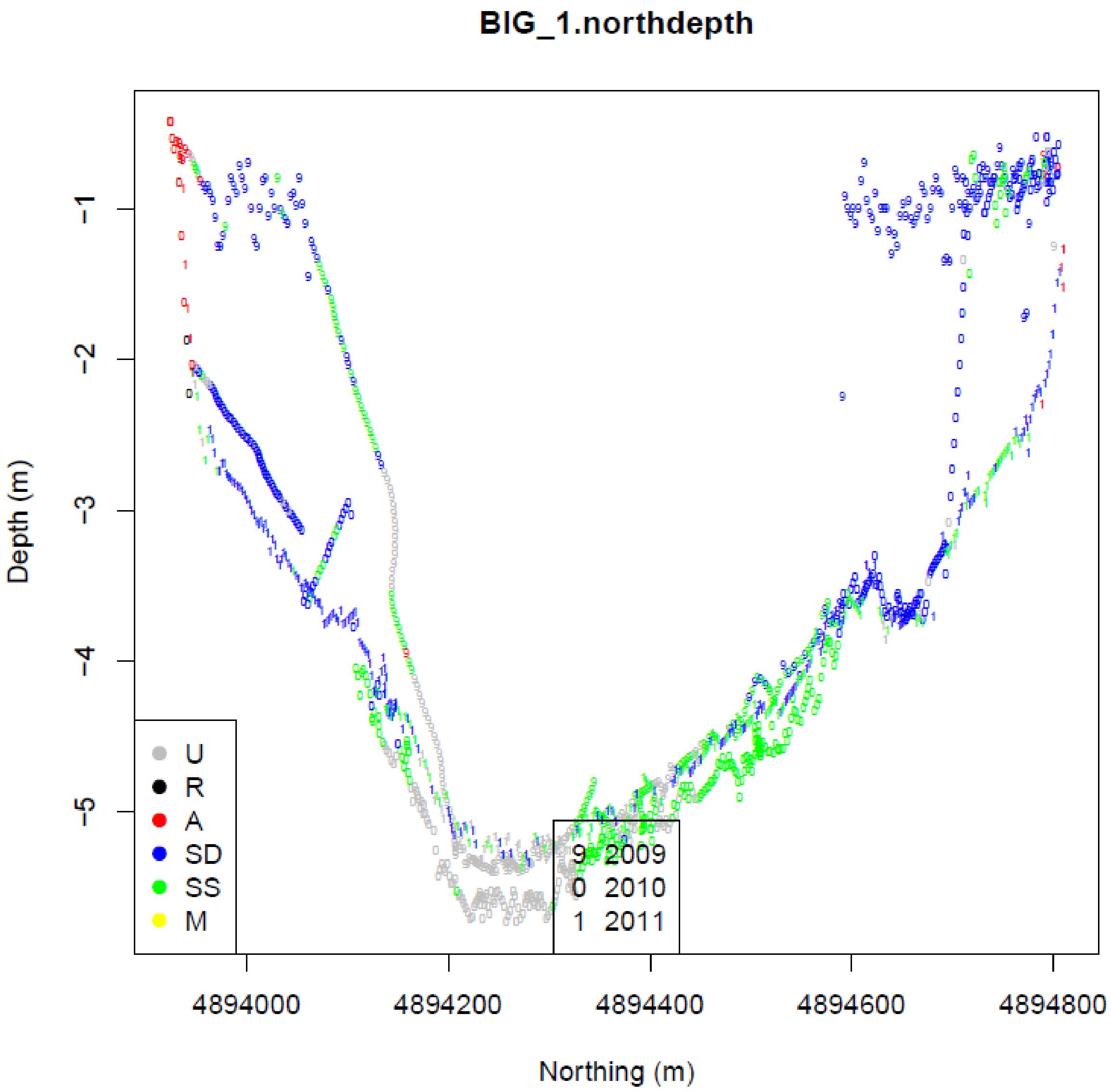

NAT_4.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4893600
4893650
4893700
4893750
4893800
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011

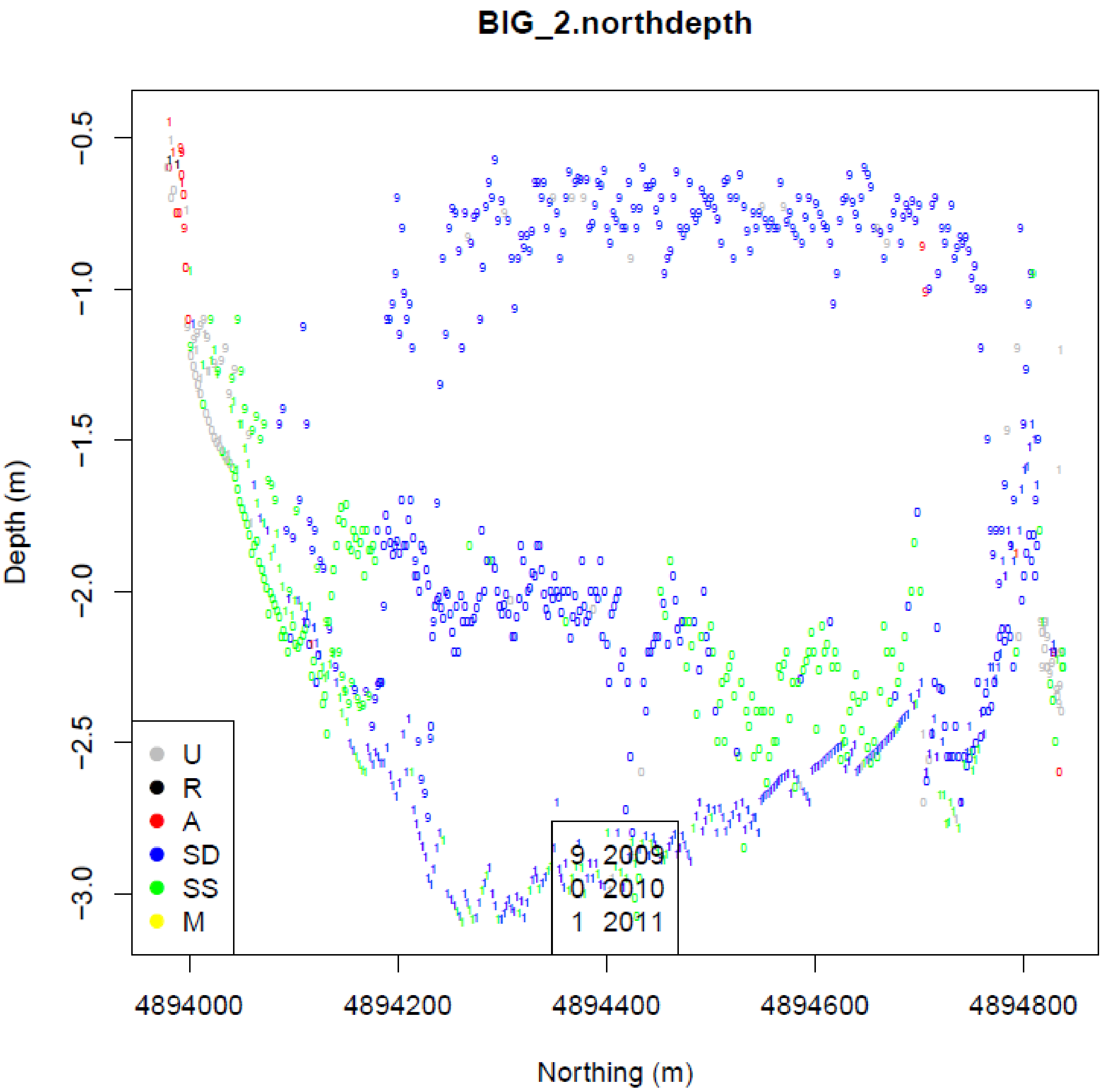

NAT_5.northdepth
Depth (m)
−1
−2
−3
−4
−5
−6
Northing (m)
4893650
4893700
4893750
4893800
4893850
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011

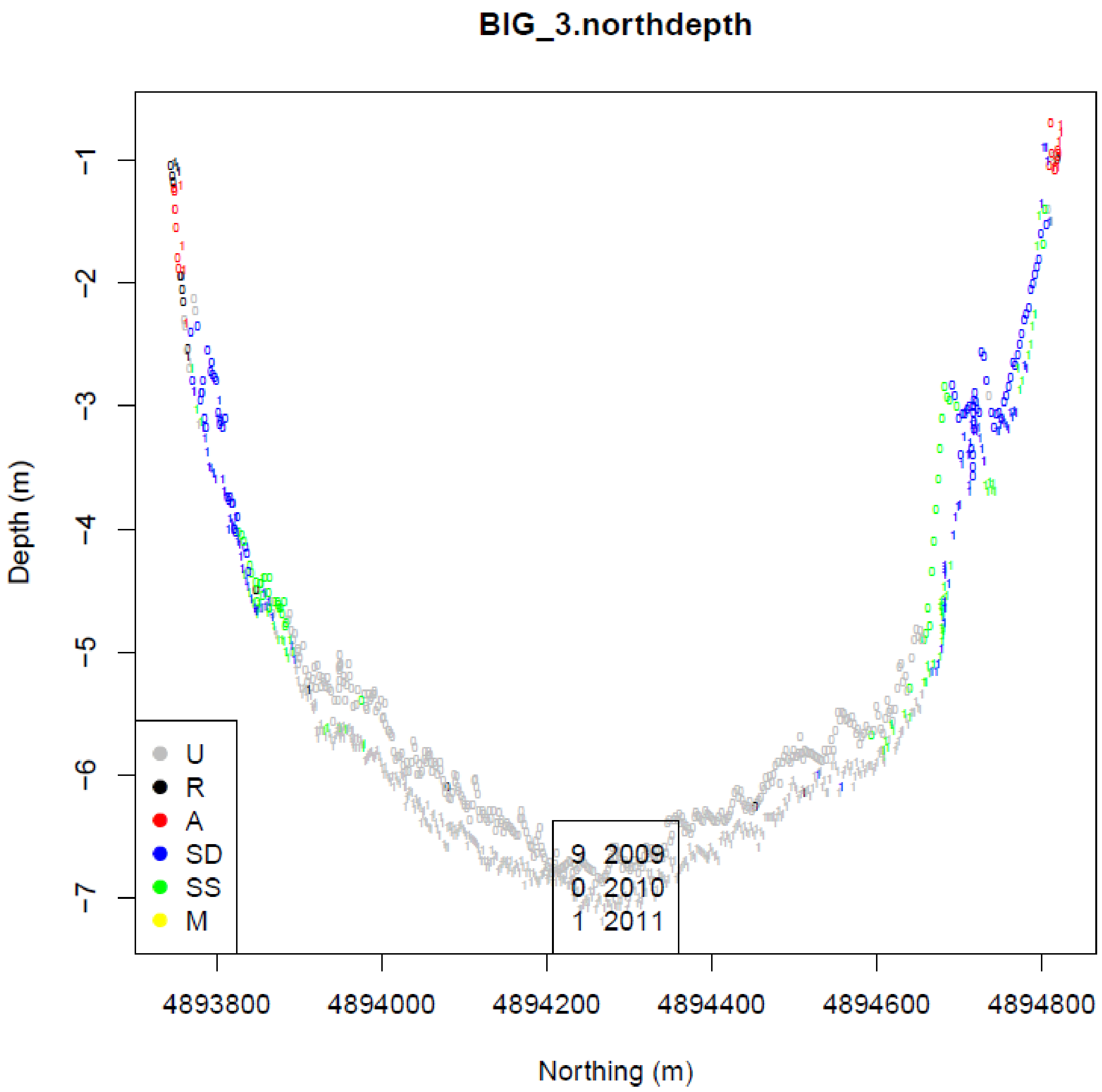

NAT_6.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
4893700
4893750
4893800
4893850
4893900
4893950
Northing (m)
U
R
A
SD
SS
M
9 2009
0 2010
1 2011

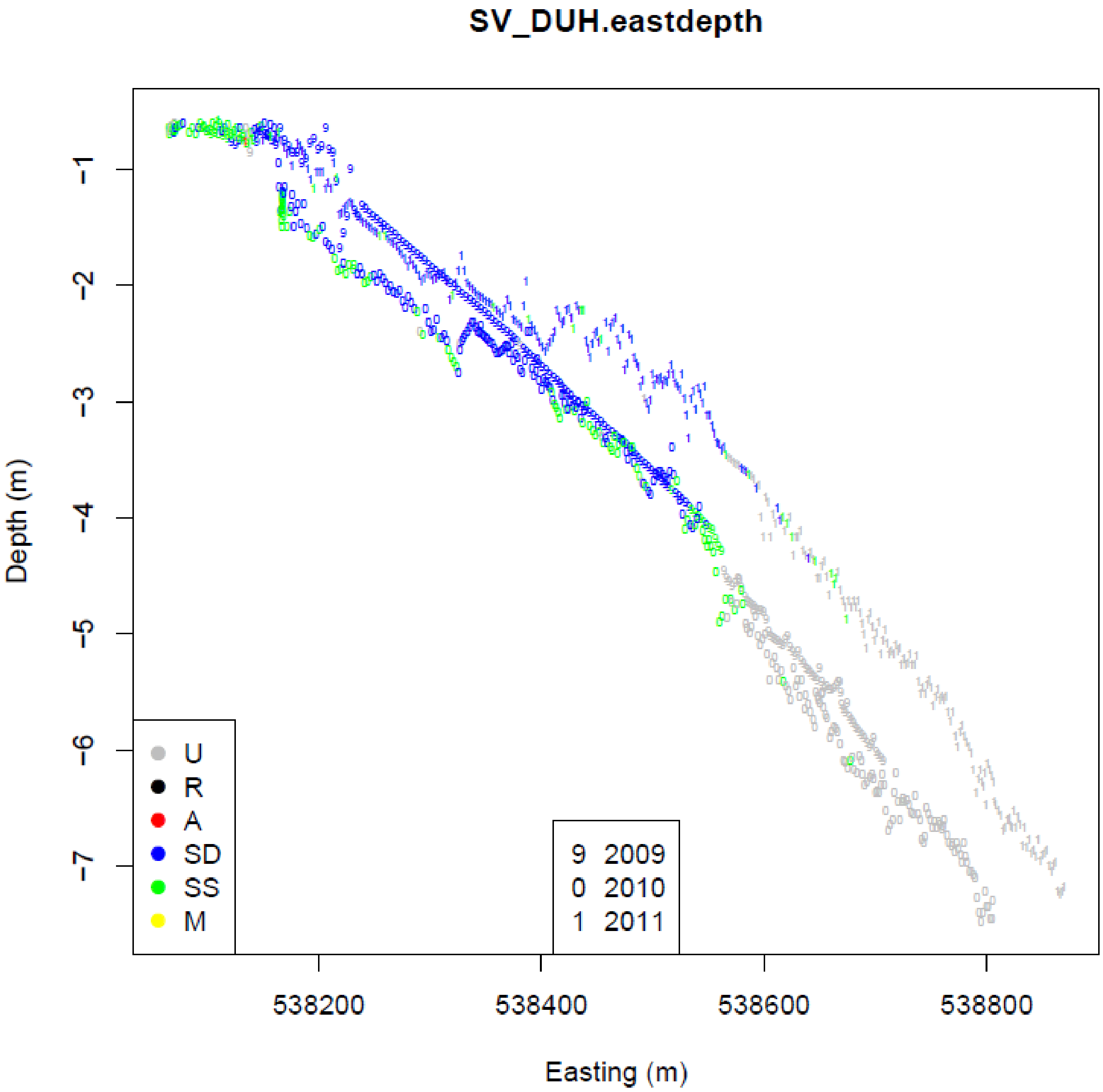

NAT_8.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
4893800
4893900
4894000
4894100
Northing (m)
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


NAT_9.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
Northing (m)
4893900
4894000
4894100
4894200
4894300
U
R
A
SD
SS
M
9 2009
0 2010
1 2011


BIG_1.northdepth
Depth (m)
-1
-2
-3
-4
-5
Northing (m)
4894000
4894200
4894400
4894600
4894800
U
R
A
SD
SS
M
9 2009
0 2010
1 2011


BIG_2.northdepth
Depth (m)
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
Northing (m)
4894000
4894200
4894400
4894600
4894800
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


BIG_3.northdepth
Depth (m)
-1
-2
-3
-4
-5
-6
-7
Northing (m)
4893800
4894000
4894200
4894400
4894600
4894800
● U
● R
● A
● SD
● SS
● M
9 2009
0 2010
1 2011


SV_DUH.eastdepth
Depth (m)
-1
-2
-3
-4
-5
-6
-7
Easting (m)
538200
538400
538600
538800
U
R
A
SD
SS
M
9 2009
0 2010
1 2011

Appendix II. Sediment accumulation, sediment erosion, gross change from unconsolidated ground to seagrass (usg), seagrass to unconsolidated ground (sgu), sparse seagrass to dense (sssd), dense seagrass to sparse (sdss) on each transect in 2009/2010 and 2010/2011.

transect	year	segment	segaccum (cm^2)	segeros (cm^2)	transectaccum (cm^2)	transecteros (cm^2)	usg (cm)	sgu (cm)	sssd (cm)	sdss (cm)	tran	side
POS_1_1	2009.201	1	13004.9	0	13004.9	0	0	0	5.39	1.96	POS_1	POS
POS_2_1	2009.201	1	0	4687.2	3085.7	6132.42	3.72	3.72	0	2.79	POS_2	POS
POS_2_1	2009.201	2	2968.56	0	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_1	2009.201	3	0	195.3	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_1	2009.201	4	117.18	0	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_1	2009.201	5	0	624.96	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_1	2009.201	6	0	624.96	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_3_1	2009.201	1	0	90.64	1359.6	1234.97	8.6	0	0	3.44	POS_3	POS
POS_3_1	2009.201	2	0	498.52	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	3	0	45.32	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	4	0	113.3	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	5	45.32	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	6	0	33.99	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	7	158.62	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	8	0	22.66	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	9	0	45.32	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	10	0	22.66	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	11	226.6	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	12	0	45.32	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	13	203.94	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	14	453.2	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	15	226.6	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	16	0	317.24	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_1	2009.201	17	45.32	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_4_1	2009.201	1	1150	0	1843.75	2625	19.69	16.11	5.37	5.37	POS_4	POS
POS_4_1	2009.201	2	0	556.25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	3	0	431.25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	4	0	68.75	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	5	0	306.25	NA	NA	NA	NA	NA	NA	POS_4	POS

POS_4_1	2009.201	6	0	556.25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	7	0	12.5	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	8	625	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	9	0	187.5	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	10	0	393.75	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	11	0	37.5	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	12	68.75	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_1	2009.201	13	0	75	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4.2_1	2009.201	1	0	302.72	75.68	2667.72	3	0	0	0	POS_4.2	POS
POS_4.2_1	2009.201	2	0	151.36	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_1	2009.201	3	0	491.92	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_1	2009.201	4	0	1589.28	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_1	2009.201	5	0	75.68	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_1	2009.201	6	0	56.76	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_1	2009.201	7	75.68	0	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_5_1	2009.201	1	579.6	0	3063.6	496.8	28.86	0	8.88	8.88	POS_5	POS
POS_5_1	2009.201	2	165.6	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	3	0	62.1	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	4	0	20.7	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	5	0	20.7	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	6	372.6	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	7	82.8	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	8	207	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	9	1242	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	10	0	165.6	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	11	0	41.4	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	12	165.6	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	13	0	165.6	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	14	62.1	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	15	0	20.7	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_1	2009.201	16	186.3	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_6_1	2009.201	1	0	208.68	14398.92	243.46	25.06	3.58	19.69	3.58	POS_6	POS
POS_6_1	2009.201	2	34.78	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_1	2009.201	3	0	34.78	NA	NA	NA	NA	NA	NA	POS_6	POS

POS_6_1	2009.201	4	69.56	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_1	2009.201	5	17.39	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_1	2009.201	6	11112.21	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_1	2009.201	7	1425.98	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_1	2009.201	8	1739	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_7_1	2009.201	1	12211.48	0	12211.48	0	16.31	13.98	6.99	36.8	POS_7	POS
NAT_1_1	2009.201	1	0	4255.8	0	4255.8	2.4	0	0	NA	NAT_1	NAT
NAT_2_1	2009.201	1	0	476.1	641.7	1656	12.48	0	4.68	3.12	NAT_2	NAT
NAT_2_1	2009.201	2	0	828	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	3	82.8	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	4	0	103.5	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	5	0	62.1	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	6	165.6	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	7	62.1	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	8	331.2	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_1	2009.201	9	0	186.3	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_3_1	2009.201	1	14929.9	0	14929.9	0	9.52	0	3.57	0	NAT_3	NAT
NAT_4_1	2009.201	1	4325	0	9878.3	553.6	7.34	0	4.41	4.41	NAT_4	NAT
NAT_4_1	2009.201	2	17.3	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	3	0	397.9	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	4	0	34.6	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	5	51.9	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	6	17.3	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	7	0	69.2	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	8	4722.9	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	9	415.2	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	10	0	51.9	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_1	2009.201	11	328.7	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_5_1	2009.201	1	6487.8	0	6903	778.5	5.56	0	1.39	0	NAT_5	NAT
NAT_5_1	2009.201	2	17.3	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_1	2009.201	3	0	34.6	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_1	2009.201	4	17.3	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_1	2009.201	5	0	17.3	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_1	2009.201	6	69.2	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT

NAT_5_1	2009.201	7	311.4	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_1	2009.201	8	0	726.6	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_6_1	2009.201	1	NA	0	3149.4	1601.9	20	0	8	2	NAT_6	NAT
NAT_6_1	2009.201	2	0	54.3	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	3	36.2	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	4	0	126.7	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	5	398.2	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	6	0	90.5	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	7	0	579.2	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	8	199.1	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	9	144.8	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	10	0	18.1	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	11	162.9	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	12	0	108.6	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	13	0	27.2	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	14	253.4	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	15	434.4	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	16	705.9	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	17	108.6	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	18	687.8	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	19	0	524.9	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	20	18.1	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_1	2009.201	21	0	72.4	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_8_1	2009.201	1	0	359.1	28.4	3213	0	0	12.5	2.5	NAT_8	NAT
NAT_8_1	2009.201	2	28.4	0	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_1	2009.201	3	0	2853.9	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_9_1	2009.201	1	6677.8	0	9005.4	1603.2	9.38	18.75	12.5	15.63	NAT_9	NAT
NAT_9_1	2009.201	5	0	761.2	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	6	397.9	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	7	0	103.8	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	8	397.9	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	9	259.5	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	10	0	43.8	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	11	968.8	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT

NAT_9_1	2009.201	12	0	286	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	13	242.2	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	14	0	259.5	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	15	61.3	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	16	0	61.3	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	17	0	43.8	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_1	2009.201	18	0	43.8	NA	NA	NA	NA	NA	NA	NAT_9	NAT
SV_DUH_1	2009.201	1	50	0	525	12962.5	36.82	15.78	31.56	199.88	SV_DUH	NA
SV_DUH_1	2009.201	2	0	37.5	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	3	25	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	4	100	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	5	75	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	6	75	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	7	0	9300	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	8	0	400	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	9	0	175	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	10	175	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	11	0	50	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	12	25	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_1	2009.201	13	0	3000	NA	NA	NA	NA	NA	NA	SV_DUH	NA
BIG_1_1	2009.201	NA	NA	NA	NA	NA	57.1	51.39	39.97	91.36	BIG_1	NA
BIG_2_1	2009.201	NA	NA	NA	NA	NA	77.84	27.8	0	233.52	BIG_2	NA
3MISO_1_1	2009.201	1	18.45	0	1206.63	1845	74.1	7.41	111.15	44.46	3MISO_1	NAT
3MISO_1_1	2009.201	2	0	7.38	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	3	7.38	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	4	0	1693.71	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	5	0	29.52	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	6	3.69	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	7	0	7.38	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	8	11.07	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	9	0	18.45	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	10	261.99	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	11	904.05	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_1	2009.201	12	0	88.56	NA	NA	NA	NA	NA	NA	3MISO_1	NAT

3MISO_2_1	2009.201	1	0	187.92	118.32	798.66	6.4	0	7.68	17.92	3MISO_2	POS
3MISO_2_1	2009.201	2	17.4	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	3	0	266.22	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	4	5.22	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	5	0	33.06	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	6	0	62.64	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	7	26.1	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	8	0	3.48	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	9	1.74	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	10	0	109.62	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	11	13.92	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	12	0	8.7	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	13	8.7	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	14	0	90.48	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	15	45.24	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	16	0	24.36	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_2_1	2009.201	17	0	12.18	NA	NA	NA	NA	NA	NA	3MISO_2	POS
3MISO_3_1	2009.201	1	0	198.36	636.12	1631.34	7.14	28.56	74.97	3.57	3MISO_3	POS
3MISO_3_1	2009.201	2	0	13.68	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	3	0	61.56	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	4	27.36	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	5	0	304.38	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	6	27.36	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	7	0	3.42	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	8	6.84	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	9	0	10.26	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	10	0	116.28	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	11	41.04	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	12	3.42	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	13	0	191.52	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	14	13.68	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	15	0	27.36	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	16	17.1	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	17	0	13.68	NA	NA	NA	NA	NA	NA	3MISO_3	POS

3MISO_3_1	2009.201	18	0	17.1	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	19	3.42	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	20	0	133.38	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	21	123.12	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	22	0	20.52	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	23	294.12	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	24	0	417.24	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	25	78.66	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_1	2009.201	26	0	102.6	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_4_1	2009.201	1	21.48	0	1764.94	248.81	21.48	16.11	3.58	1.79	3MISO_4	POS
3MISO_4_1	2009.201	2	130.67	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	3	3.58	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	4	0	3.58	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	5	599.65	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	6	0	245.23	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	7	957.65	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	8	42.96	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_1	2009.201	9	8.95	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_5_1	2009.201	1	34.56	0	1326.24	494.64	17.85	3.57	46.41	21.42	3MISO_5	POS
3MISO_5_1	2009.201	2	0	41.04	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	3	0	17.28	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	4	140.4	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	5	0	8.64	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	6	2.16	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	7	473.04	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	8	0	8.64	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	9	12.96	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	10	0	401.76	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	11	4.32	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	12	0	6.48	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	13	21.6	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	14	0	8.64	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	15	8.64	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	16	0	2.16	NA	NA	NA	NA	NA	NA	3MISO_5	POS

3MISO_5_1	2009.201	17	30.24	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	18	345.6	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_1	2009.201	19	252.72	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS
POS_1_2	2010.2011	1	0	18428.22	NA	18428.22	NA	NA	1.47	0.98	POS_1	POS
POS_2_2	2010.2011	1	5937.12	0	7655.76	4804.38	4.65	3.72	4.65	0	POS_2	POS
POS_2_2	2010.2011	2	0	39.06	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	3	937.44	0	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	4	0	3320.1	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	5	0	78.12	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	6	781.2	0	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	7	0	312.48	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_2_2	2010.2011	8	0	1054.62	NA	NA	NA	NA	NA	NA	POS_2	POS
POS_3_2	2010.2011	1	135.96	0	13573.34	815.76	10.32	3.44	5.16	30.96	POS_3	POS
POS_3_2	2010.2011	2	2198.02	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_2	2010.2011	3	181.28	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_2	2010.2011	4	0	113.3	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_2	2010.2011	5	67.98	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_2	2010.2011	6	0	702.46	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_3_2	2010.2011	7	10990.1	0	NA	NA	NA	NA	NA	NA	POS_3	POS
POS_4_2	2010.2011	1	0	1256.25	2825	2043.75	8.95	25.06	0	10.74	POS_4	POS
POS_4_2	2010.2011	2	712.5	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	3	0	18.75	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	4	818.75	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	5	0	6.25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	6	206.25	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	7	0	18.75	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	8	643.75	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	9	0	712.5	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	10	18.75	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	11	0	6.25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	12	0	25	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	13	393.75	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4_2	2010.2011	14	31.25	0	NA	NA	NA	NA	NA	NA	POS_4	POS
POS_4.2_2	2010.2011	1	37.84	0	4957.04	0	3	3	0	0	POS_4.2	POS

POS_4.2_2	2010.2011	2	189.2	0	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_2	2010.2011	3	889.24	0	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_4.2_2	2010.2011	4	3840.76	0	NA	NA	NA	NA	NA	NA	POS_4.2	POS
POS_5_2	2010.2011	1	5485.5	0	11488.5	600.3	4.44	35.52	0	15.54	POS_5	POS
POS_5_2	2010.2011	2	0	600.3	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_5_2	2010.2011	3	6003	0	NA	NA	NA	NA	NA	NA	POS_5	POS
POS_6_2	2010.2011	1	1737.81	0	9319.85	6382.13	12.53	21.48	14.32	37.59	POS_6	POS
POS_6_2	2010.2011	2	243.46	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	3	0	4956.15	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	4	0	17.39	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	5	0	1408.59	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	6	330.41	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	7	121.73	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_6_2	2010.2011	8	6886.44	0	NA	NA	NA	NA	NA	NA	POS_6	POS
POS_7_2	2010.2011	1	136.9	0	136.9	10034.77	30.29	20.97	46.6	16.31	POS_7	POS
POS_7_2	2010.2011	2	0	9624.07	NA	NA	NA	NA	NA	NA	POS_7	POS
POS_7_2	2010.2011	3	0	410.7	NA	NA	NA	NA	NA	NA	POS_7	POS
NAT_1_2	2010.2011	1	0	484.4	0	2197.1	2.4	0	0	0	NAT_1	NAT
NAT_1_2	2010.2011	2	0	484.4	NA	NA	NA	NA	NA	NA	NAT_1	NAT
NAT_1_2	2010.2011	3	0	1228.3	NA	NA	NA	NA	NA	NA	NAT_1	NAT
NAT_2_2	2010.2011	1	103.5	0	1014.3	765.9	4.68	4.68	37.44	0	NAT_2	NAT
NAT_2_2	2010.2011	2	20.7	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	3	82.8	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	4	0	144.9	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	5	103.5	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	6	186.3	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	7	0	248.4	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	8	0	62.1	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	9	20.7	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	10	0	41.4	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	11	0	269.1	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_2_2	2010.2011	12	496.8	0	NA	NA	NA	NA	NA	NA	NAT_2	NAT
NAT_3_2	2010.2011	1	0	21434.7	968.8	21573.1	4.76	0	10.71	4.76	NAT_3	NAT
NAT_3_2	2010.2011	2	968.8	0	NA	NA	NA	NA	NA	NA	NAT_3	NAT

NAT_3_2	2010.2011	3	0	138.4	NA	NA	NA	NA	NA	NA	NAT_3	NAT
NAT_4_2	2010.2011	1	0	1816.5	743.9	4463.4	16.17	0	11.76	4.41	NAT_4	NAT
NAT_4_2	2010.2011	2	86.5	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	3	0	34.6	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	4	173	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	5	0	1470.5	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	6	0	553.6	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	7	86.5	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	8	0	294.1	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	9	0	294.1	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	10	17.3	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_4_2	2010.2011	11	380.6	0	NA	NA	NA	NA	NA	NA	NAT_4	NAT
NAT_5_2	2010.2011	1	0	8434.15	1599.88	8486.32	4.17	6.95	5.56	NA	NAT_5	NAT
NAT_5_2	2010.2011	2	121.73	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_2	2010.2011	3	0	34.78	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_2	2010.2011	4	34.78	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_2	2010.2011	5	0	17.39	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_5_2	2010.2011	6	1443.37	0	NA	NA	NA	NA	NA	NA	NAT_5	NAT
NAT_6_2	2010.2011	1	0	173.9	1382.51	2878.04	14	28	14	8	NAT_6	NAT
NAT_6_2	2010.2011	2	0	712.99	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	3	295.63	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	4	0	86.95	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	5	52.17	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	6	0	34.78	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	7	43.48	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	8	0	43.48	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	9	34.78	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	10	191.29	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	11	0	208.68	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	12	0	260.85	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	13	0	1356.41	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_6_2	2010.2011	14	765.16	0	NA	NA	NA	NA	NA	NA	NAT_6	NAT
NAT_8_2	2010.2011	1	245.7	0	784.35	1512	0	0	8	8	NAT_8	NAT
NAT_8_2	2010.2011	2	0	1398.6	NA	NA	NA	NA	NA	NA	NAT_8	NAT

NAT_8_2	2010.2011	3	37.8	0	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	4	0	18.9	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	5	47.25	0	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	6	0	37.8	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	7	207.9	0	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	8	0	56.7	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_8_2	2010.2011	9	245.7	0	NA	NA	NA	NA	NA	NA	NAT_8	NAT
NAT_9_2	2010.2011	1	0	1286.56	2251.48	2459.6	21.21	0	36.36	0	NAT_9	NAT
NAT_9_2	2010.2011	2	0	889.24	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	3	37.84	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	4	0	245.96	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	5	75.68	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	6	0	37.84	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	7	37.84	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	8	75.68	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	9	624.36	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	10	794.64	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_9_2	2010.2011	11	605.44	0	NA	NA	NA	NA	NA	NA	NAT_9	NAT
NAT_10_2	2010.2011	1	229.46	0	2805.67	714.46	61.44	10.24	66.56	30.72	NAT_10	NAT
NAT_10_2	2010.2011	2	1533.21	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	3	260.75	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	4	0	20.86	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	5	0	10.43	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	6	0	26.08	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	7	0	344.19	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	8	187.74	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	9	0	31.29	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	10	0	166.88	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	11	20.86	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	12	0	52.15	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	13	52.15	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	14	187.74	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	15	0	52.15	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	16	20.86	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT

NAT_10_2	2010.2011	17	0	10.43	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	18	10.43	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	19	52.15	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
NAT_10_2	2010.2011	20	250.32	0	NA	NA	NA	NA	NA	NA	NAT_10	NAT
SV_DUH_2	2010.2011	1	25	0	35250	175	63.12	26.3	42.08	47.34	SV_DUH	NA
SV_DUH_2	2010.2011	2	0	75	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_2	2010.2011	3	0	100	NA	NA	NA	NA	NA	NA	SV_DUH	NA
SV_DUH_2	2010.2011	4	35225	0	NA	NA	NA	NA	NA	NA	SV_DUH	NA
BIG_1_2	2010.2011	1	0	2637.96	6861.66	3956.94	182.72	28.55	222.69	97.07	BIG_1	NA
BIG_1_2	2010.2011	2	14.82	0	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	3	0	859.56	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	4	74.1	0	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	5	14.82	0	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	6	6580.08	0	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	7	177.84	0	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	8	0	59.28	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	9	0	326.04	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_1_2	2010.2011	10	0	74.1	NA	NA	NA	NA	NA	NA	BIG_1	NA
BIG_2_2	2010.2011	1	NA	NA	NA	NA	33.36	33.36	233.52	72.28	BIG_2	NA
BIG_3_2	2010.2011	1	317.24	0	317.24	16360.52	78.54	28.56	64.26	35.7	BIG_3	NA
BIG_3_2	2010.2011	2	0	135.96	NA	NA	NA	NA	NA	NA	BIG_3	NA
BIG_3_2	2010.2011	3	0	226.6	NA	NA	NA	NA	NA	NA	BIG_3	NA
BIG_3_2	2010.2011	4	0	6050.22	NA	NA	NA	NA	NA	NA	BIG_3	NA
BIG_3_2	2010.2011	5	0	9947.74	NA	NA	NA	NA	NA	NA	BIG_3	NA
3MISO_1_2	2010.2011	1	0	14.76	996.3	298.89	14.82	14.82	74.1	22.23	3MISO_1	NAT
3MISO_1_2	2010.2011	2	18.45	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	3	918.81	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	4	0	11.07	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	5	0	158.67	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	6	51.66	0	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	7	0	114.39	NA	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_1_2	2010.2011	8	7.38	0	2613.72	NA	NA	NA	NA	NA	3MISO_1	NAT
3MISO_2_2	2010.2011	1	36.54	0	52.2	0	0	1.28	1.28	1.28	3MISO_2	POS
3MISO_2_2	2010.2011	2	15.66	0	NA	NA	NA	NA	NA	NA	3MISO_2	POS

3MISO_3_2	2010.2011	1	NA	0	499.32	157.32	3.57	32.13	3.57	7.14	3MISO_3	POS
3MISO_3_2	2010.2011	2	0	95.76	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	3	6.84	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	4	0	27.36	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	5	6.84	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	6	0	10.26	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	7	0	10.26	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	8	297.54	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	9	0	13.68	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	10	171	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_3_2	2010.2011	11	17.1	0	NA	NA	NA	NA	NA	NA	3MISO_3	POS
3MISO_4_2	2010.2011	1	314	0	1857	142	12.53	14.32	0	37.59	3MISO_4	POS
3MISO_4_2	2010.2011	2	1073	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	3	39	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	4	0	3	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	5	0	3	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	6	245	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	7	0	1	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	8	17	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	9	0	11	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	10	90	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	11	0	57	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	12	0	1	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	13	4	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	14	19	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	15	0	32	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	16	0	18	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	17	0	4	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	18	56	0	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_4_2	2010.2011	19	0	12	NA	NA	NA	NA	NA	NA	3MISO_4	POS
3MISO_5_2	2010.2011	1	196.56	0	205.2	51.84	0	10.71	7.14	17.85	3MISO_5	POS
3MISO_5_2	2010.2011	2	0	4.32	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_2	2010.2011	3	0	28.08	NA	NA	NA	NA	NA	NA	3MISO_5	POS
3MISO_5_2	2010.2011	4	8.64	0	NA	NA	NA	NA	NA	NA	3MISO_5	POS

3MISO_5_2	2010.2011	5	0	19.44	NA	NA	NA	NA	NA	NA	3MISO_5	POS

10. BIOGRAFIJA

Melita Mokos (rođ. Bacalja) rođena je 13. svibnja 1980. godine u Zadru gdje završava osnovnu i srednju školu. Akademske godine 2001/2002 upisuje se na diplomski studij Sveučilišnog studijskog centra za studije mora Sveučilišta u Splitu, gdje završava smjer „Biologija i ekologija mora“. Diplomski rad s temom „Morfološke i reproduktivne značajke alge *Dictyota dichotoma* (Hudson) J. V. Lamouroux var. *intricata* (C. Agardh) Greville na području Splita”, pod vodstvom prof.dr.sc. Borisa Antolića, obranila je u siječnju 2007. godine. Međusveučilišni poslijediplomski doktorski studij „Primijenjene znanosti o moru“ pri Sveučilištu u Splitu i Sveučilištu u Dubrovniku upisuje u akademskoj godini 2009/2010 te pod vodstvom izv.prof.dr.sc. Stewart Schultza sa Sveučilišta u Zadru izrađuje ovu doktorsku disertaciju. U ožujku 2009. zaposlena je na MZOS projektu „Ekologija i praćenje stanja bentoskih životnih zajednica hrvatskoga Jadrana“ kao znanstveni novak na Pomorskom odjelu Sveučilišta u Zadru, a od listopada 2014. radi na Odjelu za ekologiju, agronomiju i akvakulturu Sveučilišta u Zadru.

Pored navedenog projekta, sudjelovala je kao suradnik na projektu Europskog socijalnog fonda „Istraživanje kvalitete i promidžba NOVigradske DAgnje – INOVaDA“ kojeg provodi Odjel za ekologiju, agronomiju i akvakulturu. Na Sveučilištu u Zadru sudjeluje u izvođenju nastave iz kolegija: „Zaštita mora i morskog okoliša“ i „Onečišćenje vodenih sustava“

Tijekom poslijediplomskog studija sudjelovala je u Erasmus+ Programu pri čemu je provela tjedan dana na Sveučilištu Cadiz u Španjolskoj na Fakultetu znanosti o moru i okolišu.

Koautor je jednog znanstvenog rada u časopisu indeksiranom ISI Web of knowlegde bazi, jednim radom u časopisu indeksiranom u Biosis Citation Indeks bazi te jednog rada koji je trenutno u postupku recenzije. Sudjelovala je u nekoliko domaćih i međunarodnih znanstvenih i stručnih skupova sa ukupno osam sažetaka.

Osim navedenog, često organizira i provodi aktivnosti popularizacije znanosti kroz razne radionice namijenjene djeci od vrtićke do srednjoškolske dobi čime na neformalan način doprinosi provođenju edukacije iz područja znanosti o moru. Aktivni je član European Marine Science Educators Association (EMSEA) koja promiče znanje o moru (engl. „ocean literacy“) te je koordinator za djelovanje EMSEA grupe za područje Mediterana (EMSEA-Med).

Popis radova

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1. Kruschel, C., Schultz, S., **Bacalja, M.**, Dahlke, S. 2009. Evidence for seagrass competition in a central Croatian Adriatic lagoon. *Annales, Series Historia Naturalis*, 19 (1); 45-54.

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7. **Mokos, M.**, Kruschel, C., Schultz, S.T. Increases in seagrass cover are paralleled by decreases in benthic slope along DGPS- and depth tracked video monitoring transects in a Central Adriatic embayement. *Proceedings of the Mediterranean Seagrass Workshop 09*, Hvar, Croatia, 2009.

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