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A STUDY ON *POSIDONIA OCEANICA* (L.) Delile, 1813 SEAGRASS MEADOWS IN THE LEVANT SEA

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in

Marine Biology and Fisheries
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by

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A STUDY ON *POSIDONIA OCEANICA* (L.) Delile, 1813 SEAGRASS MEADOWS IN THE LEVANT SEA

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BİLLUR ÇELEBİ

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Approval of the Graduate School of Marine Sciences

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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Prof. Dr. Ferit Bingel
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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

A STUDY ON *POSIDONIA OCEANICA* (L.) Delile, 1813

SEAGRASS MEADOWS IN THE LEVANT SEA

ÇELEBİ, Billur

M. Sc., Department of Marine Biology and Fisheries

Supervisor: Assoc. Prof. Ali Cemal GÜCÜ

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In this thesis, the distribution and state of *Posidonia oceanica* meadows along the Turkish coast of the north eastern Mediterranean was investigated. The study area was a unique site due to the presence of eastern geographical limit of *Posidonia oceanica* meadows in Mediterranean Sea. It was aimed to assess the possible reasons of the absence and/or regression in relation to environmental changes. The study was conducted from September 2004 to January 2007 in 5 main regions between Anamur/Mersin and Samandag/Hatay. The regions were determined according to the presence/absence of *Posidonia oceanica* meadows; 1 region including the boundary meadow at the geographical distribution limit, 1 region western and 3 regions eastern to that boundary meadow.

To describe the hydrological characteristics of the study area temperature, salinity and light were measured as abiotic descriptors. Additionally sedimentological analysis was carried out to check the suitability of the substrate type for *Posidonia oceanica* colonization. The main differences between the regions were found in temperature and light conditions. Both, the recordings of temperature loggers at 10 and 15 meter depths and the sea surface temperature retrieved from satellite (NOAA-AVHRR) showed that the eastern stations with no *Posidonia oceanica* meadows were warmer than the western stations.

Consequently in this study the maximum tolerable temperature limit for *Posidonia oceanica* growth was determined as 28.4°C from the data collected by the temperature loggers placed to natural meadows near to the boundary meadow. Generally, the whole study area had a limiting light condition for seagrass growth due to low penetration depths of the 10% of surface irradiation. This was a generalized minimum light requirement for growth of seagrasses. Especially in Mersin and Iskenderun bays the minimum required light level did not reached deeper than 10 meter depths in coastal stations.

The biological parameters of the *Posidonia oceanica* meadows were investigated under 3 complementary methods in the first two regions. The structural descriptors were measured *in-situ*. The lowest shoot density and leaf lengths were found to be in boundary meadow. This meadow had also the lowest depth limit among other stations. The functional descriptors were examined by the lepidochronological and phenological analysis in laboratory. Most of the measurements varied either with respect to depth or among stations according to the abiotic factors of the stations. The lepidochronological cycles obtained from sheath thicknesses were further correlated with abiotic descriptors via a mathematical model.

Finally, the first transplantation experiment of *Posidonia oceanica* along Turkish coasts has been conducted in 2 regions where presently no meadows exist. The survival of cuttings in one station indicated the success of the methodology, while the failure in other stations provided information on the possible reasons of absence/degradation of natural meadows in the area. These included the destructive impact of bottom trawling, the high pressure of grazing (the potential causes of Lessepsian migration) and the long term changes in climate resulting in alterations of environmental conditions such as increasing temperature and reduced light penetration.

Keywords: *Posidonia oceanica*, North Eastern Mediterranean, lepidochronology, transplantation, temperature

ÖZ

LEVANT DENİZİ *POSIDONIA OCEANICA* (L.) Delile, 1813

DENİZÇAYIRLARI ÜZERİNE BİR ÇALIŞMA

ÇELEBİ, Billur

Yüksek Lisans Tezi, Deniz Biyolojisi ve Balıkçılık Bölümü

Tez Yöneticisi: Doç. Dr. Ali Cemal GÜCÜ

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Bu yüksek lisans tez çalışmasında, Türkiye kıyılarındaki *Posidonia oceanica* deniz çayırlarının Kuzey Doğu Akdeniz dağılımı ve durumu incelenmiştir. Çalışma alanı *Posidonia oceanica* deniz çayırlarının Doğu Akdeniz'deki coğrafi dağılımının sınırını içerdiğinden ayrı bir öneme sahiptir. Tez çalışmasının ana amacı *Posidonia oceanica* deniz çayırlarının bölgede bulunmama veya geri çekilme sebeplerinin çevresel değişimlerle ilişkilendirilerek araştırılmasıdır. Çalışma, Anamur/Mersin ve Samandağ/Hatay arasında kalan kıyı şeridinde seçilen beş ana bölgede Eylül 2004 - Ocak 2007 tarihleri arasında gerçekleştirilmiştir. Bölgelerin belirlenmesinde *Posidonia oceanica* deniz çayırlarının bulunup bulunmaması esas alınmıştır. Buna göre dağılımın coğrafik sınırındaki *Posidonia oceanica* yatağını içeren 1, sınırın batısında 1, doğusunda 3 olmak üzere toplam 5 bölge seçilmiştir.

Çalışma alanının hidrolojik özelliklerinden deniz suyu sıcaklığı, tuzluluğu ve ışık geçirgenliği ölçülmüştür. Ek olarak taban yapısının *Posidonia oceanica* çayırlarının yetişmesine uygunluğunu kontrol etmek için sediman tane boyu analizi yapılmıştır. Bölgede temel farklılıklar sıcaklık ve ışık ölçümlerinde tespit edilmiştir. 10 ve 15 metre derinliklerine yerleştirilen sıcaklık kayıt cihazlarından alınan veriler ile, uydudan (NOAA-AVHRR) alınan yüzey suyu sıcaklık verilerinin her ikisinde de *Posidonia oceanica* deniz çayırlarının bulunmadığı doğu istasyonlarında sıcaklığın batıdaki istasyonlara göre daha yüksek olduğu gözlenmiştir. Bu çalışma sırasında coğrafik sınırın doğusunda doğal olarak

bulunan *Posidonia oceanica* deniz çayırlarına yerleştirilen sıcaklık kayıt cihazlarından elde edilen veriler doğrultusunda, *Posidonia oceanica* deniz çayırlarının büyüyebilmesi için dayanabileceği en yüksek sıcaklık 28.4°C olarak belirlenmiştir.

Çalışma alanında genel olarak yüzey ışımasının %10'u sığ derinliklerde soğurulduğundan, bölgedeki düşük ışık geçirgenliğinin deniz çayırlarının büyümesini sınırlayan bir faktör olduğu tespit edilmiştir. Özellikle Mersin ve Iskenderun körfezlerinde kıyısal istasyonlarda *Posidonia oceanica* deniz çayırlarının büyümesi için gerekli en düşük ışık seviyesi 10 metre'den daha derine ulaşamamıştır.

Posidonia oceanica deniz çayırları ile ilgili biyolojik parametreler çayırların doğal olarak bulunduğu batıdaki ilk iki bölgede bütünleyici 3 yöntem ile araştırılmıştır. Çayırların yapısal özellikleri asıl yerinde sualtı örneklemesi ile incelenmiştir. En düşük filiz yoğunluğu ve yaprak boyu Kuzey Doğu Akdeniz'de coğrafi sınırı oluşturan deniz çayırı yatağında bulunmuştur. Bu yatak aynı zamanda incelenen diğer istasyonlara göre en düşük derinlik sınırına sahiptir. Fonksiyonel özellikler ise lepidokronoloji ve fenolojik analiz yöntemleri ile laboratuarda gerçekleştirilmiştir. Ölçümlerin çoğu derinliğe veya istasyonlardaki çevresel koşullara bağlı olarak farklılık göstermiştir. Lepidokronoloji yöntemi ile elde edilen kın (kabuk) kalınlığındaki döngüsel değişimler matematiksel model kullanılarak abiyotik parametrelerle ilişkilendirilmiştir.

Son olarak, sınırın doğusunda kalan ve *Posidonia oceanica* deniz çayırlarının günümüzde bulunmadığı iki bölgede Türkiye sahillerinde bilinen ilk *Posidonia oceanica* nakil ve ekimi gerçekleştirilmiştir. Ekilen filizlerin batıda kontrol amaçlı seçilen bir istasyonda deney süresince hayatta kalabilmesi kullanılan yöntemin uygun olduğunu gösterirken; diğer istasyonlarda ekilen filizlerin istenilen başarıyı elde edememesi bölgede eski kaynakçalarda doğal olarak bulunduğu belirtilen *Posidonia oceanica* deniz çayırı yataklarının yok olması veya gerilemesinin olası sebepleri hakkında bilgi sağlamıştır. Bu nedenler arasında dip trolünün tahrip edici etkisi, Lessepsiyen göçü ve otlamanın etkisi, uzun dönemli iklimsel değişimlerin sebep olduğu çevresel değişimler (sıcaklık artışı ve ışık geçirgenliğinin azalması) yer almaktadır.

Anahtar Kelimeler: *Posidonia oceanica*, Kuzey Doğu Akdeniz, lepidokronoloji, nakil ve ekim, sıcaklık

To My Grandmother

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1. INTRODUCTION

Seagrasses are valuable habitats because they are ecologically and economically important components of the coastal ecosystems worldwide (Green and Short, 2003). They exist as extensive beds on all the world's continents except Antarctica. However expanding of human population and continuously increasing disproportionately in coastal areas are resulting in declined or totally destroyed seagrass beds in many locations. These alterations made the comprehensive overview of coastal resources and critical habitats more important than ever.

Seagrasses are unique because they are the only group of flowering plants that have recolonised the sea. Their evolution gives insights for their succession. Thereof in this chapter firstly the evolution of seagrasses will be presented. Then the biology and ecological role of this plant will be given since this plant play an important role in the ecosystem. Finally an outline on present distribution of *Posidonia oceanica* will be given and state of seagrasses will be underlined.

1.1 Evolution of Seagrasses

Seagrasses, confined to the marine environment, are aquatic angiosperms (Larkum *et. al.*, 2006). They comprise <0.02% of the angiosperm flora in the earth (Hemminga and Duarte, 2000). This represents a small number of species (about 50) when compared with any other group of marine organisms. Although this small size can be considered as an indicator of recent origin, fossil records and indirect evidences, such as fossils from associated fauna, fail to support this belief. Contrary they have an early origin in evolution of angiosperms. There are evidences indicating that colonization of marine environment by angiosperms took place about 100 million years ago. This is relatively early when the origin of the appearance of angiosperms is accepted about 400 million years ago. Coastal plants and freshwater hydrophytes are suspected to be the ancestors for seagrasses (Hemminga and Duarte, 2000).

Most of the seagrasses are entirely adapted to marine environment although some species cannot reproduce unless emergent at low tide or subject to fresh water inflow. On the other hand some of them can survive in different conditions such as fresh water, estuarine, or hyper saline waters (Short and Coles, 2001).

Originating from land they have evolved several key adaptations for marine life (Dawes, 1998). These include:

- The possession of creeping rhizomes;
- A reduced cuticle that lacks stomata;
- Hydrophilous pollination, which allows submarine pollination or pollination by surface rafts of pollen (e.g. *Zostera spp*.);
- A reduced xylem;
- The presence of gas filled lacunae (aerenchyma) transversed by diaphragms which prevent entry of water in damaged plants.
- Large, longitudinally extended lacunae, named as "air canals". These air canals are characteristic of all seagrass leaves. There are several hypotheses for the role of such canals. One suggests that the main role of the aerenchyma is to deliver O_2 to the roots, allowing survival in anoxic conditions found in mudflats. However another role of the aerenchyma might be to reduce O_2 demand by decreasing the amount of tissue requiring oxygen.

Although these marine plants are called as "seagrass" and resemble morphologically the terrestrial grass species, botanically they are classified within the monocotyledonous plants.

Globally there are relatively few species of seagrasses and these are grouped in 12 genera and 5 families (Den Hartog, 1970, c.f. Larkum *et. al.*, 2006). Generally, they are divided into five temperate and seven tropical genera (Larkum *et. al.*, 2006). However, there are many exceptions to this classification. The warmer temperate seas are dominated by the genus *Posidonia* (Short and Coles, 2001).

The genus *Posidonia* contains 9 species (Larkum *et. al.*, 2006). Only one of them, *Posidonia oceanica*, is endemic to the Mediterranean ecosystem. All other 8 species are found around south coasts of Australia. A comparison between the Mediterranean species *Posidonia oceanica* and the Australian species *Posidonia angustifolia*, *Posidonia australis*, *Posidonia sinuosa* and *Posidonia ostenfeldii*

show large DNA sequence divergence between the south and north temperate oceans (Waycott *et. al.*., 1997).

The following taxonomic hierarchy for *Posidonia oceanica* (L.) Delile (1813) is compiled from URL 1, URL 2, URL 3, URL 4 and Group (2003);

Kingdom	Plantae– Plants
Subkingdom	Tracheobionta– Vascular plants
Superdivision	Spermatophyta– Seed plants
Division	Magnoliophyta– Flowering plants
Class	Liliopsida– Monocotyledons
Subclass	Alismatales–
Order	Najadales-
Family	Posidoniaceae (Hutchinson, 1934)
Genus	*Posidonia* (K.D. Koenig, 1805)
Species	*Posidonia oceanica* (L.) Delile, 1813 – Mediterranean tapeweed

These taxonomic hierarchies are still disputed and there are considerable arguments over the nomenclature and taxonomic relations of the seagrasses because the definition of seagrasses at species level is far from satisfactory in certain genera (Short and Coles, 2001). Thus in coming years there may be changes to the accepted classification and hence to the number of species considered to be seagrasses (Green and Short, 2003).

1.1.1 Biology of seagrasses (and *Posidonia oceanica*)

Posidonia oceanica meadows extend from shallow waters to depths of about 40 meter. They form monospecific meadows which differ in coverage pattern and shoot density (Borg *et. al.*, 2005). The shoot density can change between 150 and 300 shoots/m^2 (very sparse beds), or may be more than 700 shoots/m^2, (very dense beds) (Giraud, 1977, c.f. Larkum *et. al.*, 2006). The shoots rise from roots in two different modes; vertically or horizontally. Vertical shoots are called orthotropic and they avoid burial, while the horizontal shoots are called plagiotropic which enable colonization. The leaves coming out from shoots trap

sediments thus accumulate inorganic and organic matter (Gacia and Duarte, 2001). These silting and the growth of both shoot types form a typical terraced structure which is defined as matte (Figure 1.1). Matte consists of intertwining strata of rhizomes, roots and sediments (Larkum *et. al.*, 2006). This structure causes the rise of bed to surface in shallow waters. The average accretion rate of refractory organic matter is around 0.175 cm per year and they remain with little alteration for millennia (Mateo *et. al.*, 1997). Thus the age of debris in some meadows can be more than 3000 years. When there is space, the shoots grow horizontally first in order to colonize the space (Boudereque and Meinesz, 1982, c.f. Larkum *et. al.*, 2006). Thereof it has wide spacing between vertical shoots in first colonization process.

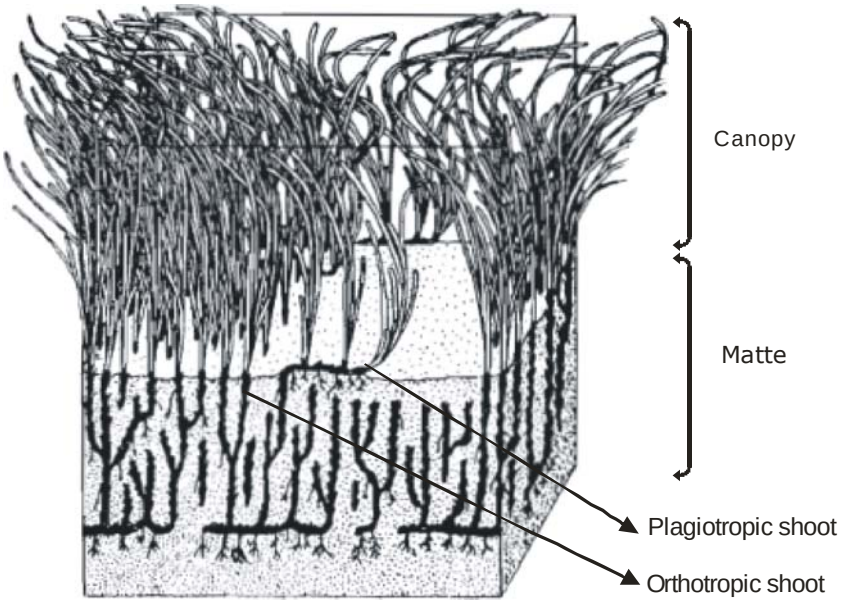


Figure 1.1 Schematic diagram of *Posidonia oceanica* matte structure (modified from Boudouresque and Meinesz, 1982, c.f. Larkum *et. al.*, 2006).

In the succession order they are at the end, being the climax community (den Hartog, 1971, c.f. Hemminga and Duarte, 2000). For the development of *Posidonia oceanica*, the substratum should be rich in organic matter. Thus firstly the pioneer species *Caulerpa prolifera*, *Cymodocea sp.* and *Zostera sp.* settle and produce suitable sediments. These enable the seed germination and shoot growth of *Posidonia oceanica*. Then the settled meadows with long leaves cause

the decline of light at the bottom, in turn the pioneer species disappear (Boudouresque and Meinesz, 1982, c.f. Larkum *et. al.*, 2006).

A coarse grained sandy substratum is the most preferred sediment for *Posidonia oceanica* growth (Mazzella *et. al.*., 1993). However it can grow also on sediments ranging from soft to rock unless it is muddy. This species is stenohaline (can not tolerate salinity changes). It occurs between 33 - 40 ppt (hypersaline environment in eastern Mediterranean, Pergent and Zaouali, 1992, c.f. Larkum *et. al*., 2006). However some experimental studies found out deleterious effects over 39 ppt (Larkum *et. al., 2006*). *Posidonia oceanica* is not resistant to desiccation, thus it is not a intertidal species as opposed to their Australian relatives. It can tolerate the temperature range between 9-29°C (Boudouresque and Meinesz, 1982, c.f. Larkum *et. al., 2006*).

In general *Posidonia* genus is a seagrass with long life-span (70-350 days), high biomass and productivity (Pergent-Martini *et. al*., 1994; Hemminga and Stapel, 1999; Marba and Walker, 1999). However it has differences in leaf biometry among species. Also there are variations for the same species with respect to location and depth. *Posidonia oceanica* show decreasing plant growth and shoot density with depth. It has seasonality in shoot biometry and consequently in overall biomass due to the seasonal changes of temperature and light. This is reflected by the annual cycle of leaves' appearance, fall and growth rhythm (Figure 1.2). All year round juvenile leaves are present appearing more from September till November. The life span of a leaf varies between 7-12 months depending on the month of appearance. Although storm induce leaf breakage and fall, the old leaves necrose throughout the year. The leaf breakage occurs from the point which is called ligule thus leaving the leaf base attached to the shoots. These (called sheath) are persistent and contribute to matte structure. The seasonal variability is low for rhizome biomass because the shoot density is relatively constant throughout the year. Related to nutrient availability shoots show highest growth in February and lowest growth in August. The interannual variation in biomass can be explained via the availability of sources: the leaf length increase in fast growing dense beds, but when a factor becomes limiting the density decrease and thus resources become available again. By this way they prevent shoot mortality. This indicates the interconnection of shoots and rhizomes and their coactions.

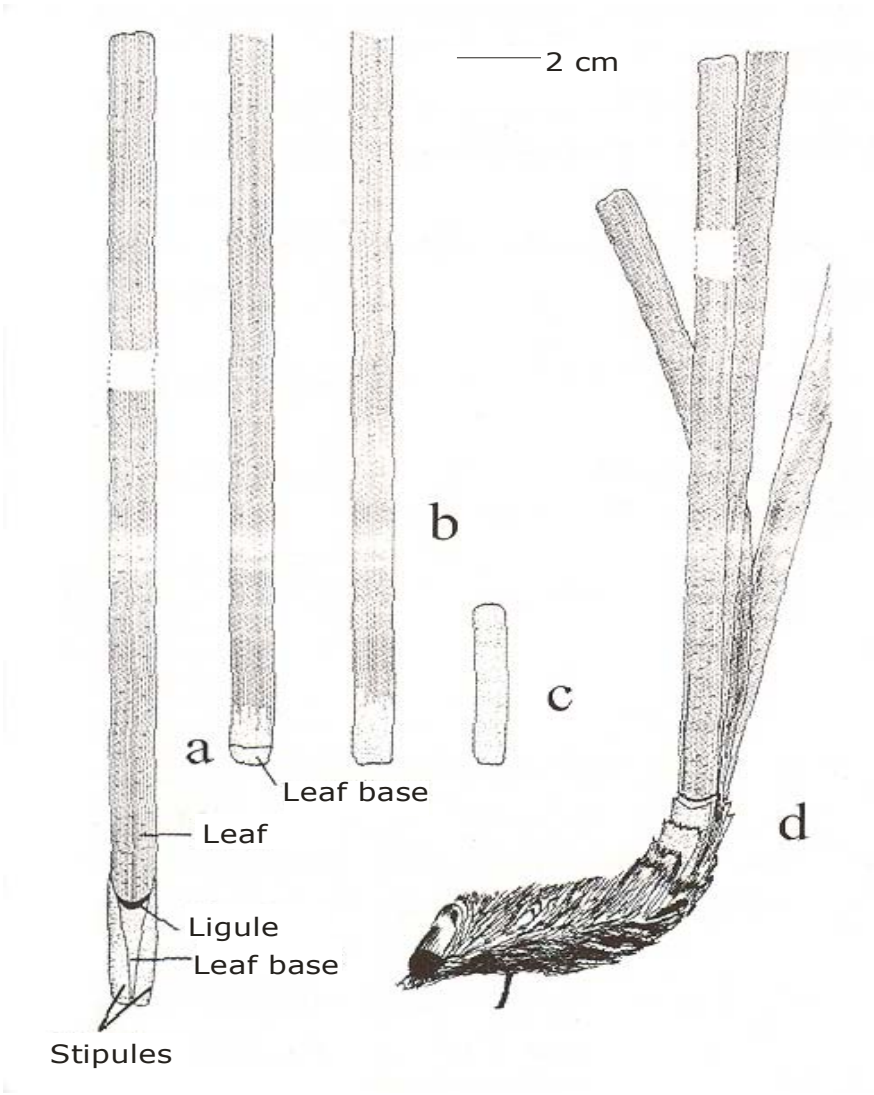


Figure 1.2 *Posidonia oceanica*, a) adult leaves, b) intermediate leaf, c) juvenile leaf, d) rhizome covered scales (old sheats) and leaf shoot (Buia *et. al*., 2004).

The genus *Posidonia* can reproduce both asexually (elongation of rhizomes and erection of new shoots) or sexually (flowering and seed production). However reproduction through flowering is at most once a year and show spatial and interannual variability. Although the exact causes of these variations are still not known, they have attributed to genetic variation or shoot age (Balestri and Vallerini, 2003), distribution of active meristems or small scale differences in environment or temperature (Marba and Walker, 1999; Campey *et. al*., 2002).

The emergence of flower buds occurs between April and June. Starting from July anthesis continues until September. This is followed by fruit and seed development. The shedding happens between November and January (Cambridge and Hocking, 1997; Gobert *et. al*., 2001). Flowering requires additional nutrients because it affects the nutrient reserves of fruit (Cambridge and Hocking, 1997; Gobert *et. al*., 2005). When germinations starts first plumule develops and then a primary root at the radical pole protrude. After 10 days 2 or 3 leaves come out from the apical meristem and additional adventitious roots appear. The leaf number continues to increase until 9 months with the development of one primordial tap-root. This stage is critical because the mortality is high (Balestri and Cinelli, 2003). The seedlings of *Posidonia oceanica* grow horizontally at a rate of 5-10 cm per year and develop their own rhizomes (Boudouresque and Meinesz, 1982, c.f. Larkum *et. al.*, 2006). The success of sexual reproduction may be altered due to grazing of inflorescences (Piazzi *et. al.*, 2000).

In Mediterranean *Posidonia oceanica* flowering was observed in 1961, 1967, 1971, 1972, 1973, 1975, 1979, 1981, 1982 and 1983 (Pergent and Pergent-Martini, 1990) and in 1994 (Sandmeier *et. al.*, 1999) and in 2003 (Diaz-Almela *et. al.*, 2007). This is a rare event in cold water of north-western Mediterranean shores, whereas it is more common in southern and eastern Mediterranean (Molinear and Picard, 1952, c.f. Larkum *et.al*., 2006).

1.1.2 Ecological role of seagrasses (and *Posidonia oceanica*)

Seagrass meadows, forming a complex ecosystem (Figure 1.3), provide many different goods and ecological services (Borum *et. al.*, 2004). These goods (e.g. finfish and shellfish) can be used directly by humans, while the ecological services (e.g. biodiversity maintenance) are beneficial indirectly though the improvement of marine environment.

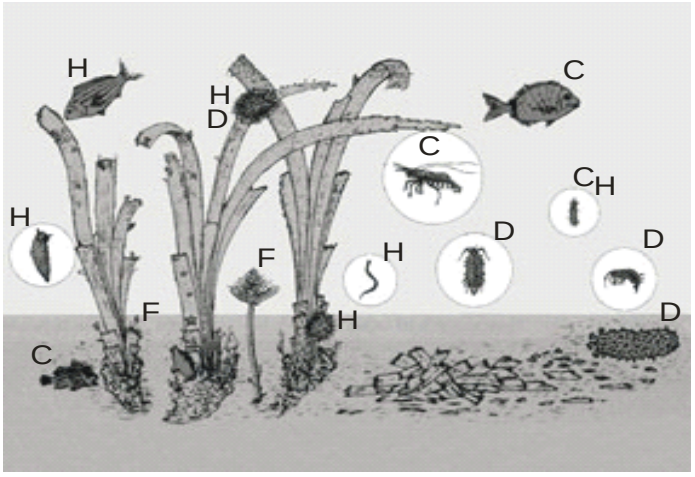


Figure 1.3 Representation of seagrass ecosystem (Boudouresque and Meinesz, 1982, modified and c.f. from Larkum *et. al.*, 2006).

H: herbivore, C: carnivore, D: detritivore, F: filter feeder.

Their importance is recognized over the last quarter of the 20th century (Larkum *et. al.*, 2006). They are considered from one of the ecosystem engineers due to their ability to change numerous aspects of their environment (Table 1.1). Their goods and services are referred as "ecosystem services" and their average global value due this services are calculated as 19.000 \$ ha^{-1} y^{-1} (Costanza *et. al.*., 1997).

Table 1.1 Seagrass functions and their ecosystem values from a wider perspective (from Green and Short, 2003).

FUNCTION	ECOSYSTEM VALUE
Primary production – including benthic and epibenthic production	Seagrasses are highly productive, and play a critical role as food for many herbivores. This productivity lies at the base of the food chain and is also exported to adjacent ecosystems.
Canopy structure	The growing structures of seagrasses provide a complex three dimensional environment, used as a habitat, refuge and nursery for numerous species, including commercially important fish and shellfish.
Epiphyte and epifaunal substratum	The large surface area of seagrass above ground biomass provides additional space for epiphytes and epifauna, supporting high secondary productivity.
Nutrient and contaminant filtration	Seagrasses help to both settle and remove contaminants from the water column and sediments, improving water quality in the immediate environment and adjacent habitats.
Sediment filtration and trapping	The canopy of seagrasses help to encourage settlement of sediments and prevents resuspension, while the root systems help to bind sediments over longer term, improving water quality and in some places helping to counter sea-level rise.
Creating below-ground structure	The complex and often deep structures of the seagrass roots and rhizomes support overall productivity and plan a critical role in binding sediments.
Oxygen production	The oxygen released from photosynthesis helps improve water quality and support faunal communities in seagrasses and adjacent habitats
Organic production and export	Many seagrass ecosystems are net exporters of organic materials, supporting estuarine and offshore productivity.
Nutrient regeneration and recycling	Seagrasses hold nutrients in a relatively stable environment, and nutrient recycling can be relatively efficient, supporting overall ecosystem productivity.
Organic matter accumulation	Along with sediments the organic matter of roots, rhizomes and even leaves can remain bound within the sediment matrix, or accumulate on adjacent coastlines or habitats, building up the level of the benthos and supporting other food webs.
Wave and current energy dampening	By holding and binding sediments, and by preventing the scouring action of waves directly on the benthos, seagrasses dampen the effects of wave and current energy, reduce processes of erosion, reduce turbidity and increase sedimentation.
Seed production and vegetative expansion	Seagrasses are capable of both self maintenance and spreading to new areas via sexual and asexual reproduction.
Self sustaining ecosystem	The complex community of seagrass ecosystem support important biodiversity and provides trophic interactions with other important ecosystems such as coral reefs, mangroves, salt marshes and shellfish reefs.
Carbon sequestration	As perennial structures, seagrasses are one of the few marine ecosystems which store carbon for relatively long periods. in a few places such carbon may be bound into sediments or transported into the deeper oceans and thus play an important role in long term carbon sequestration.

1.2 Distribution of *Posidonia oceanica* in Mediterranean

Posidonia oceanica has differentiated from the other *Posidonia* species by its distribution (Green and Short, 2003). It is endemic to Mediterranean Sea (Figure 1.4). It is also genetically different than other *Posidonia sp.* According to DNA sequencing studies (Waycott and Les, 2000) it has been estimated that two groups separated relatively early, probably in Late Eocen. Previously it was postulated that the origin of this genus arose from Tethys Sea, but reconstruction of the position of shallow seas corresponding to that time are not convincing as potential seagrass habitats (Hemminga and Duarte, 2000).

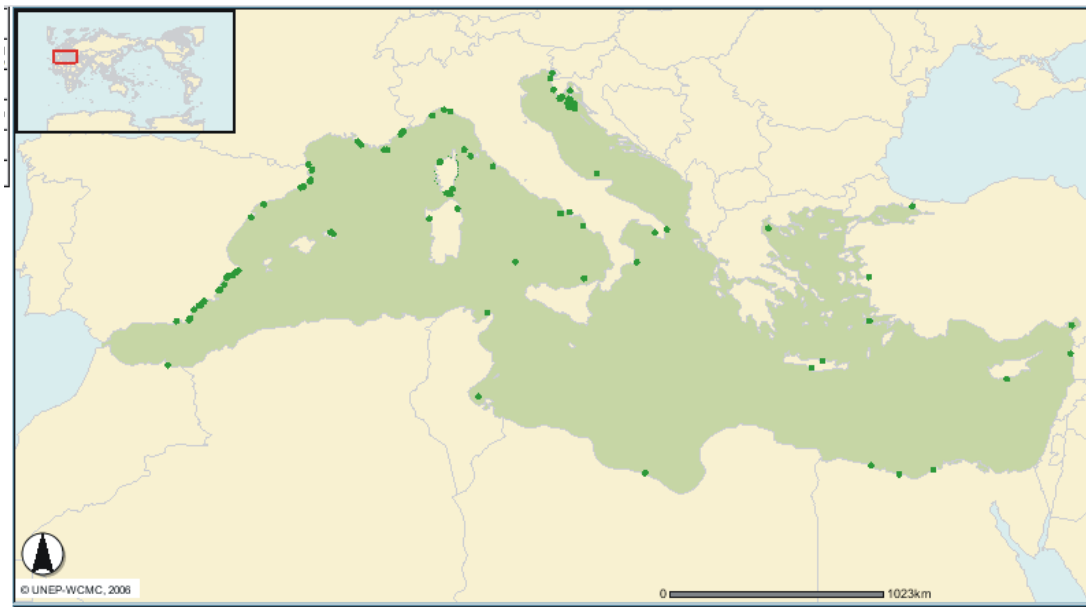


Figure 1.4 The distribution of *Posidonia oceanica* meadows according to UNEP-World Conservation Monitoring Center (URL 5).

According to present estimates; the meadows of *Posidonia oceanica* occupy 25.000-50.000 km^2 (Pasqualini *et. al.*, 1998). There are also several other seagrass species in Mediterranean Sea, however *Posidonia oceanica* is generally considered the dominant species among the other 9 seagrasses. In the western Mediterranean the complex of *Posidonia oceanica, Cymodocea nodosa* and *Zostera noltii* occupy fairly predictable zones. The intertidal is occupied by *Zostera noltii* to *Cymodocea nodosa* and at deeper parts meadows of *Posidonia*

oceanica occur. In the Mediterranean, *Zostera marina* is present in the open ocean (France, Italy, Spain), but also regularly in coastal lagoons of the Western Mediterranean (Laugier *et. al..,* 1999), where it is often found with *Zostera noltii*.

In eastern Mediterranean the seagrass beds are based mainly on one species. From these *Posidonia oceanica* forms denser meadows, although they may be invaded by algae species when there is deterioration in the environment such as pollution (Green and Short, 2003). On the other hand *Cymodocea nodosa* beds are accompanied by *Caulerpa prolifera* most of the time (Lipkin, 1977, cited in Green and Short, *2003*). A change in eastern Mediterranean was the increase of *Halophila stipulacea* distribution after its introduction from the Red Sea due to the opening of the Suez Canal (Short, 2001).

In early descriptions of western Egyptian coasts Aleem (1955, c.f. Green and Short, 2003) stated the presence of *Posidonia oceanica.* He also mentioned the stabilization of seagrass beds at Al Iskandariya. Later they became affected due to domestic and industrial pollution and started to decline (Mostafa, 1991, cited in Green and Short, 2003). And in the eastern part of Egyptian coasts *Posidonia oceanica* was reported as small stands by Aleem (1955, c.f. Green and Short, 2003) at that time. Since then the status of these sites are not recorded for long time (Green and Short, 2003). According to a more recent monitoring by Mostofa (2000) it was mentioned that the Eastern area in front of the Nile Delta, east from Abu Qir and in between Rosetta and Damietta provided no records of *Posidonia oceanica* meadows. In Israeli coasts only *Cymodocea nodosa* and *Zostera noltii* were found on sandy bottoms at sheltered sites (Lipkin, 1977, c.f. Mostafa, 2000). The author did not record *Posidonia oceanica* in the area from Bardaweel lagoon to the waters of Israel. These coasts were highly exposed to wind and wave action due to lack of any bays. In Lebanese coasts there were not effective investigations to judge the seagrasses there (Green and Short, 2003).

Thus there are only 2 countries at the far end of the eastern Mediterranean, where the healthy meadows of *Posidonia oceanica* are still persisting; Cyprus and Turkey. On Cyprus coasts rich stands of *Posidonia oceanica* and *Cymodocea nodosa* were common (Green and Short, 2003). However the quick spread of green alga *Caulerpa racemosa* was considered as a threat for the healthy meadows of the island (Argyrou *et. al*., 1999).

There are very few studies concerning the distribution of *Posidonia oceanica* meadows around the Turkish coasts, especially in south eastern coasts. According to Cirik (1986) *Posidonia oceanica* meadows were present in Mersin / Akkuyu Bay. In 2006, a series of studies were made by Aysel *et. al*. (2006a, b, c) in Mersin, Adana and Hatay for the marine algae and seagrass composition of these areas. Within the frame of these investigations in all regions, 5 seagrass species (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera noltii*, *Zostera marina* and *Halophila stipulacea*) were reported.

1.2.1 Factors regulating growth and distribution

The fate of seagrass meadows is dependent to a number of general parameters. These include physical parameters that regulate the physiological activity of seagrasses (temperature, salinity, waves, currents, depth, substrate and day length), natural phenomena that limit the photosynthetic activity of the plants (light, nutrients, epiphytes and diseases), and anthropogenic inputs that inhibit the access to available plant resources (nutrient and sediment loading). The various combinations of these parameters can permit, encourage or eliminate seagrass growth (Short, 2001).

Individually the most important effects of these parameters can be summarized as follows:

Light; The visible light has two properties which are important for photosynthesis; intensity and quality (Dawes, 1998). Marine plants respond to both of these changes during transmittance through seawater. According to Hellebust (1970, c.f. Dawes, 1998) the responses of marine plants can be functional or structural. Functional responses include photoacclimation through pigments production; changes in photosynthetic rates, as shown by sun and shade responses; reorientation of chloroplasts, phototactic and phototrophic responses; and initiation of reproduction due to photoperiod signals to short and long day plants. Structural responses include changes in morphology and cytological structure.

The magnitude of light penetration is much lesser in water than air (Hemminga and Duarte, 2000). Thereof light intensity decreases with water depth very rapidly even in clear ocean waters. Additional to absorption by seawater, particulate and soluble substances increase the total attenuation of light in water

column. The intensity of absorption varies with the wavelength. In coastal areas light transmission is much lower because of high loads of particles and dissolved organic material. Consequently the depth limit for PAR (Photosynthetically active radiation) penetration varies from less than a meter to several tens of meters and accordingly the vertical distribution of seagrass restricted to a narrower depth range. As an example the maximum depth for a seagrass was recorded as 90m (*Halophila sp*.) (Taylor, 1928, c.f. Hemminga and Duarte, 2000), although majority of seagrass are confined to depths of less than 20m (Hemminga and Duarte, 2000).

According to Duarte (1991) 11% of surface irradiation emerged as the critical limit from an overall data set of different seagrasses. But there were also higher values recorded. Other complications in light requirements include: same species may require different light conditions in different habitats; plants may be sensitive not only to total irradiance but also to spectral composition; the wavelength pattern of light can change due to scattering and absorption in water; unpredictable periods of high turbidity can be produced due to combination of land run-off, phytoplankton bloom, wind and mixing.

Temperature; The light was considered the most important abiotic factor in growth and survival due to its involvement in photosynthesis. On the other hand temperature is the fundamental factor for determining the geographical distribution (Dawes, 1998). It affects chemical reactions (metabolic rates) and thus all processes of an organism. Its effectiveness range starts from cellular level and goes up to community level. In cellular mechanisms, the high temperature causes denaturation of proteins and damages enzymes and membranes, whereas low temperature causes disruption of lipids and proteins in membranes thus mechanical damage. Plants can not regulate their temperature (poikiotherms) and must adapt to their environment. Because of this pattern temperature tolerances are evaluated at many different levels: the cellular level for enzymatic reactions, the physiological level for photosynthesis and respiration, and organismal level for growth and reproduction. Exposure to increasing or decreasing ranges in temperature will cause stress in seagrasses, which is monitored as restriction in plant productivity (Grime, 1977, c.f. Dawes, 1998). For monitoring temperature tolerances of species many studies have followed the concept of Gessner (1970) (c.f. Dawes, 1998), in which he used structural and functional responses of plants. Gessner (1970, c.f. Dawes, 1998)

and Luning (1990, c.f. Dawes, 1998) pointed out the continuum among optimal temperature range where reproduction (reproduction limits) occurs, the suboptimal temperatures where only growth occurs (growth limits) and the extreme temperatures where growth ceases and death occurs (lethal limits).

Salinity; Salinity may limit both types of reproduction and therefore influences the distribution of species (Verhoeven, 1975, c.f. Short and Coles, 2001). Additionally, the changes in salinity can cause osmotic stress which in turn alters the plants' susceptibility to disease (Biebl and McRoy, 1971, c.f. Short and Coles, 2001). In overall it also play a role in the biodiversity of the seagrass ecosystems because inhabiting organism are also adapted to stable conditions of seagrass beds (Hemminga and Duarte, 2000).

Carbon; For photosynthesis beside light, carbon is an essential element. It is incorporated in numerous organic forms which are essential for physical structure and metabolic function (Hemminga and Duarte, 2000). In terrestrial environments the principal form of carbon for photosynthesis is the carbon dioxide, however in marine environments there are restrictions to the CO_2 supply due to two factors. CO_2 concentrations are relatively low because of the effect of dissolved salts (Hemminga and Duarte, 2000). And the diffusion rates are very slow compared to air. Due to these physical restrictions submerged angiosperms have an alternative source of carbon; bicarbonate. In water inorganic carbon exists in three forms; CO_2, HCO_3^- and CO_3^{2-} depending on the pH of the water (Borum *et. al.*, 2004). Thus seagrasses assimilate two of these forms (CO_2 and HCO_3^-) for photosynthesis.

A net positive carbon balance in plants is a sign of growth. This is determined by the ration between carbon fixed in photosynthesis and the consumption of organic carbon in respiration (Hemminga and Duarte, 2000). This positive balance is achieved at light levels higher than the light compensation point.

Nutrients; Nutrient dynamics in seagrass ecosystems are contradictory *(Larkum et. al.*, 2006). They are sites of high production but they occur in oligotrophic waters (e.g. Mediterranean). To sustain such a high production under low nutrient availability is a puzzling question. More paradoxically is that *Posidonia oceanica* can colonize the ultra-oligotrophic habitats in eastern Mediterranean (Larkum *et. al.*, 2006). For that purpose it has developed strategies. Due to seasonal leaf fall *Posidonia oceanica*, as many other temperate species,

periodically loose nutrients. However it can compensate this loss by nutrient acquisition (Lepoint *et. al.*., 2002), storage and remobilization (Alcoverro *et. al.*., 2000, Invers *et. al.*., 2002), photosynthate translocation (Alcoverro *et. al.*., 2000, Marba *et. al.*., 2002 b) and nutrient resorption and recycling (Alcoverro *et. al.*., 2000, Lepoint *et. al.* 2002).

Physical exposure (waves); The adaptation of marine plants to waves, currents and tides provides clues for the effects of water movement (Dawes, 1998). Waves and currents are important because they cause mechanical and chemical stress. They are controlling the upper depth limit of seagrass meadows (Borum *et. al.*, 2004). They can alter the growth and distribution of seagrasses via changing the processes such as resuspension, sedimentation, and erosion. By these they affect the light regime and can cause burial of shoots. On the other hand marine plants have adapted to their damaging effect because they increase the chance of the plant to capture the dissolved substances whose diffusion rates are much slower (10.000 times) in water than in air (Dawes, 1998). Further the diffusion of nutrient, oxygen and carbon dioxide happen through a boundary layer formed by slowly moving seawater around the plants.

Substratum, Sulphide and Oxygen; suitable substratum can facilitate the settlement of seeds, anchorage of roots and elongation of rhizomes (Borum *et. al.*, 2004). They influence the resuspension dynamics when combined with wave actions. Another role of the sediment is the habitat they are forming for other organisms. In locations with excess organic matter bacterial activity is induced, an anoxic layer close to sediment is formed and consequently the metabolic processes produce phytotoxic compounds such as sulphide (Hemminga, 1998 c.f. Hemminga and Duarte, 2000). This stress can be counterbalanced by pumping of oxygen through their roots into the sediments. This process maintains a relatively oxidized rhizosphere. However there is a conflict in this cycle. The highly productive seagrass meadows do increase organic input not only through their own detritus but also though trapping of sediments (Duarte *et. al.* 1999, Gacia *et. al.* 1999). Thus they poison themselves by driving sediment conditions to stressful levels (Hemminga and Duarte, 2000). However in the presence of iron in the sediment the sulfide is precipitated as iron-sulfur minerals and thus buffering the toxic effects (Borum *et. al.*, 2004). The oxygen supply is needed for both above and below ground tissues. The metabolism is affected negatively under anoxic conditions and toxic metabolites are produced.

Competition and grazing; These are biotic regulators for the growth of seagrasses. Competition can be observed between seagrass species during the succession period. Also other competition types between different organisms and seagrass colonization can be observed; e.g. (*Mytilus edulis*) suppress the growth of *Zostera marina* (Borum *et. al.*, 2004). A more recent antagonism type is the invasions. An example was the introduction of *Caulerpa taxifolia*, noted first in 1984 in Mediterranean (Meinesz and Hesse, 1991, c.f. Hemminga and Duarte, 2000). It may spread very rapidly and grow well on root matte of *Posidonia oceanica* (De Villele and Verlaque, 1995).

Lastly grazing plays a role on the growth of seagrasses (Borum *et. al.*, 2004). Their efficiency and ecology differ according to seagrass species (Short and Coles, 2001). They are a link in the food web. In seagrass systems there are three main pathways for the energy transfer from primary producers to the consumers. These are consumption of leaving tissue, leaf detritus and algal epiphytes (Buia *et. al.*, 2000). The relative importance of each pathway is different among species. Life history of the species, spatial patterns of meadow and chemical composition of plant material cause this variation (Zupo, 1993, c.f. Short and Coles, 2001). For example climax species such as *Posidonia oceanica* are grazed less due to defensive chemical compounds, whereas fat growing species do not spend energy for such defensive (e.g. polyphenolic) compounds (Cebraian and Duarte, 1998).

1.2.2 Hydrography of the Levant Sea

The Mediterranean Sea is an enclosed sea (Mojetta, 1996). The cold waters of Atlantic enter into the Mediterranean through the Strait of Gibraltar and flows eastwards on surface due to its low density. On the contrarily the warmer and saltier Mediterranean water flows out from below. This circulation takes the nutrient rich intermediate and deep water out of Mediterranean (Krom *et. al.*, 1991).

The most eastern part of Mediterranean is called Levant Sea and it is the hottest part of the Mediterranean (Mojetta, 1996). And the basin which is the second largest basin in eastern Mediterranean is also called Levantine (Özsoy *et. al.*, 1989). This basin is encircled by Asia Minor, the northeast African mainland and

the Cretan Archipelago. It is connected to the Aegean Sea through the narrow passages of Straits of Rhodes, Scarpanto and Kasos, whereas the connection to Ionian Sea is via the Cretan Passage. The basin is characterized generally by narrow continental shelf if the Gulf of Iskenderun and the Nile Fan are excluded.

In Levantine Basin there are four distinct water masses and these may be recognized through the vertical profiles of water column (Özsoy *et. al.*, 1991). The eastern part of this basin is covered by Levantine Surface Water (LSW) during summer (Gertman and Hecht, 2002). It is formed by intensive heating and evaporation and thus has the largest salinity and temperature of the entire Mediterranean Sea. The LSW advects to the Rhodes gyre region because of the general cyclonic circulation of Levantine basin and it is thought to be the source water for the Levantine Intermediate Water (LIW) due to large salinity (Hecht and Gertman, 2001). Then through the Cretan Arc passage it advects into eastern shelf of Aegean Sea and contribute to formation of intermediate and deep water there (Theocharis *et. al.*, 1999).

The eastern Mediterranean showed some dramatically changes after the completion of Aswan Dam in 1964, which ended the historic Nile River discharge of 90 km^3 yr^{-1} into Mediterranean (Nof, 1979, c.f. Bryden and Boscolo, 2002). According to Nof (1979, c.f. Bryden and Boscolo, 2002) the increasing Mediterranean salinity was attributed to the change in the water budgets. The diversion of river for irrigation increased the net evaporation over the Mediterranean basin by about 10% (Bryden and Boscolo, 2002). The damming of Nile river was also suggested as one of the possible reasons for the long term increase in salinity of LSW, which in turn may caused the Eastern Mediterranean Transient during 1987-99 (Klein *et. al.*, 2000).

The impacts of circulations in Mediterranean Sea on *Posidonia oceanica* have been evaluated in genetic studies. A study was conducted on 33 *Posidonia oceanica* meadows by Procaccini and Piazzi (2001) using microsatallite analysis. The results showed a low genetic density overall in *Posidonia oceanica*, though some small differences were observed among basins. Western populations were found to be more polymorphic than eastern population, where North Adriatic meadows were represented by only one clone (Ruggiero *et. al.*., 2002). Within the basin a clear genetic sub-division was defined. The existence of this genetic structure may be explained by the present circulation patterns of surface currents. These currents may influence gene flow and/or colonization of different

areas. A clear relationship can be observed in the difference of genetic structure of northern and southern populations in Tyrrhenin Sea where seasonal circulation gyres are present (Astraldi and Gasparini, 1994).

1.3 State of Seagrasses

1.3.1 Threats to seagrass ecosystems

The decline of seagrasses is reported worldwide (Short and Coles, 2001). Because they are vulnerable resources, they can be easily lost in coastal areas (Hemminga and Duarte, 2000). In many cases the declines were attributed not only to one threat but a combination of impacts (Green and Short, 2003). These can be categorized mainly into 2; natural and anthropogenic.

Natural threats include geological, meteorological and biological impacts. Geological impacts may be through rise of shoreline due to earthquakes (Johansen, 1971 c.f. Hemminga and Duarte, 2000). Meteorological impacts can act though hurricanes, floods and storms causing erosion of beds (Preen *et. al*., 1995). While biological impacts can be effective as grazing, burrowing or diseases. An example was the die-off of eelgrass (*Zostera marina*) along North Atlantic coasts in 1930s due to a marine slime mould-like protist, *Labyrinthula zosterae* Porter & Muehlstein (phylum Labyrinthulomycota) (Muehlstein *et. al.*. 1991, c.f. Ralph and Short, 2002).

Recently, the anthropogenic threats are increasing more rapidly and causing stress for environment. These are effective either in direct or indirect manners. Some of them can be listed as eutrophication, siltation, organic loading of sediments, toxic chemicals, mechanical damaging, invasion by exotic species and global changes. Their impact mechanisms are summarized below (Table 1.2).

Table 1.2 Impacts of direct and indirect human forcing on seagrass ecosystems (from Duarte, 2002).

TYPE	FORCING	POSSIBLE CONSEQUENCES	MECHANISMS
Direct impacts	Mechanical damage (e.g. trawling, dredging, push nets, anchoring, dynamite fishing)	Seagrass loss	Mechanical removal and sediment erosion
	Eutrophication	Seagrass loss	Deterioration of light and sediment conditions
	Salinity changes	Seagrass loss, changes in community structure	Osmotic shock
	Shoreline development	Seagrass loss due to burial or erosion	Seagrass uprooting
	Land reclamation	Seagrass loss	Seagrass burial and shading
	Aquaculture	Seagrass loss	Deterioration of light and sediment conditions
	Siltation	Seagrass loss and changes in community structure	Deterioration of light and sediment conditions
Indirect impacts	Seawater temperature rise	Altered functions and distributions	Increased respiration, growth and flowering, increased microbial metabolism
	Increased CO2 concentration	Increased depth limits and production	Increased photosynthesis, eventual decline of calcifying organisms
	Sea level rise and shoreline erosion	Seagrass loss	Seagrass uprooting
	Increased wave action and storms	Seagrass loss	Seagrass uprooting
	Food web alterations	Changes in community structure	Changes in sediment conditions and disturbance regimes

1.3.2 Monitoring the health of *Posidonia oceanica* meadows

To evaluate the global quality of the marine environment reliably and to apply proper management rules for the conservation of the coastal environment there is need of knowledge about organisms giving quick and easily recognizable responses to ecological changes (Kennedy and Jacoby, 1999). The use of biological indicators is often an appropriate method for that purpose.

Seagrasses in general, and *Posidonia oceanica* meadows in particular, are considered to be appropriate for biomonitoring because of their wide distribution, reasonable size, sedentary habit, easy collection and abundance and sensitivity to modifications of littoral zone (Pergent-Martini *et. al.*, 2005). From the results of a questionnaire made by these authors, which was distributed to all the identified laboratories working on this topic, a list of the most commonly used descriptors was drawn up, together with the related research techniques (Table 1.3). Accordingly the most useful techniques enabling to monitor *Posidonia oceanica* meadows can be measured both in situ and further analyzed in laboratory. Some are direct measurements of biological functions, e.g. leaf biometry; whereas some reveals information about the environmental health (e.g. contamination) and associated organisms.

Table 1.3 List of the descriptors, and the specific parameters associated (modified from Pergent, 2005).

*) indicate the parameters considered in the present study.

MEASURES IN SITU	
Upper depth limit of the meadow	*)
Lower depth limit of the meadow	Presence of ripple-marks Granulometry of the sediment *) Presence of died mattes Presence of litter Presence of algae
Density (number of shoots per surface unit)	*)
Bottom cover (surface occupied by the meadow, %)	Resistance to erosion Compactness Homogeneity Physicochemical composition
Structure of the matte	Presence of channels intermatte Presence of "cliff of dead matte" Percentage of plagiotropic rhizomes Erosion of rhizomes Burial of rhizomes Evaluation of biodiversity
MEASURES IN THE LABORATORY	
Leaf biometry	Shoot composition Origin of broken leaves Lepidochronology *) Plastochrone interval
Datation measurements	Speed of rhizomes growth *) Number of leaves per year *) Primary production *) Dating of paleoflowering *)
Biochemical and chemical composition	Proteins Lipids Carbohydrate Carbon Hydrogen Nitrogen Phosphorus Enzymes of stress
Contamination	Heavy metals
Species associated to the meadows	Borer organisms Associated fauna Epiphytic coverage Bacterial populating

1.3.3 Conservation and Restoration

Seagrasses are not a separate ecological component in marine environments and should be considered by their closely linked community types. In tropics they form complex interactions with mangrove communities and coral reef systems, whereas in temperate water they are associated with algae beds, salt marshes, bivalve reefs and epiphytic plant communities (Short and Coles, 2001). Therefore most of the management plans for seagrass protection based on the protection of wider ecological systems or designed to protect the overall biodiversity of marine environment.

In Australia and United States coastal issues are under the state or federal legislations due to the historical developments of these countries as federations of state. On the other hand in Europe and South East Asian countries these legislations are controlled by central governments (Short and Coles, 2001). In these areas marine issues are also managed through intercountry agreements such as UNEP Strategic Action Plan for the South China Sea and the Mediterranean Countries Barcelona Convention (URL 6).

The approaches for seagrass protection are mainly location specific or nation specific. Presently there is no international legislation application directly for seagrasses (Short and Coles, 2001). But still, through international conventions the values of seagrasses are globally accepted and arguments are based for their universal protection. These conventions are RAMSAR Convention, the Convention on Migratory Species of Wild Animals; and the Convention on Biodiversity. The last one from these conventions commits countries to the develop "Marine Protected Areas". In that protection system a key community which is included are the seagrasses. Thus the seagrasses are protected as a whole ecosystem under the broader philosophic concept of "sustainability" and "conservation of biodiversity".

In some areas however the protection itself is not enough for the survival of seagrasses due to increasing anthropogenic impacts (Short and Coles, 2001). Due this inclining loss of seagrass there have been methods developed to recover the seagrasses artificially (Hemminga and Duarte, 2000). However restoration is not an easy process and there are many failures due to different reasons. Thus the uncertainty of the transplantation projects emphasizes conservation over transplantation (Race and Fonseca, 1996).

Principally the rate of loss or recovery depends on to lifespan, clonal growth, and seedling recruitment of specific seagrass species (Larkum *et. al.*, 2006). *Posidonia* species regrow at the scale of decades (Meehan and West, 2000). Thus they recorded as not returning from disturbance. If the original cause of loss is removed, scales of decline for seagrasses can be compared with scales of their recovery (Larkum *et. al.*, 2006). Unfortunately for *Posidonia* species the observations of loss rate (Pergent and Pergent-Martini, 1991) showed that the perturbations occurred not less than one century letting time for recovery (Duarte, 1995). An example was the recovery of *Posidonia oceanica* beds in Cabrera Archipelago National Park in Spain (Marba *et. al.*., 2002a). According to this study regulation has improved the status of seagrasses in the park but recovery is a very slow process and thus requires centuries to be completed.

1.4 Objectives of the study

As outlined in this chapter, the importance of seagrasses have increased recently due their role in the ecosystem functioning. Species specific studies, concerning only *Posidonia oceanica,* are most commonly concentrated in western Mediterranean and they provided excessive amounts of information about its distribution, biology, ecology and genetics. However the north eastern Mediterranean coasts have been remained unnoticed.

Eventually, this study aimed to partially fill the gap of knowledge about *Posidonia oceanica* meadows in north eastern Mediterranean Sea and to provide information about their health status at the geographical distributional end. This will be tried to be achieved by the investigation of *Posidonia oceanica* both in situ and in laboratory. Further the hydrological factors that might be responsible of the absence of *Posidonia oceanica* meadows on the Eastern Mediterranean coast of Turkey should be examined.

2. MATERIALS AND METHODS

This section is divided into 5 headings according to the collection and process type of data. Description of the study area and time schedule is followed by the sampling procedures of abiotic, structural and functional parameters measured. The last section describes the first transplantation experiment of *Posidonia oceanica* in Turkey.

2.1 Study area

The study area, expanding from Anamur to Syrian border, covered the Turkish coasts in the northeastern Mediterranean Sea (Figure 2.1). The data collection sites were mainly concentrated in 5 regions along this coastline. The hydrological and biological differences between these regions were compared in this study.

The study area was monitored by 14 cruises, which were conducted from November 2004 to September 2006 by RV Lamas. During this period 5 descriptor types were investigated (Table 2.1). The stations for each descriptor type were coded according to their descriptor type and depth, where numbering of stations in each descriptor started from the western most locations.

Additional physical data, overlapping the same study period and site, were collected during the research cruises of RV Bilim. The dates and locations of these data collected by the two research vessels were mapped in Figure 2.2.

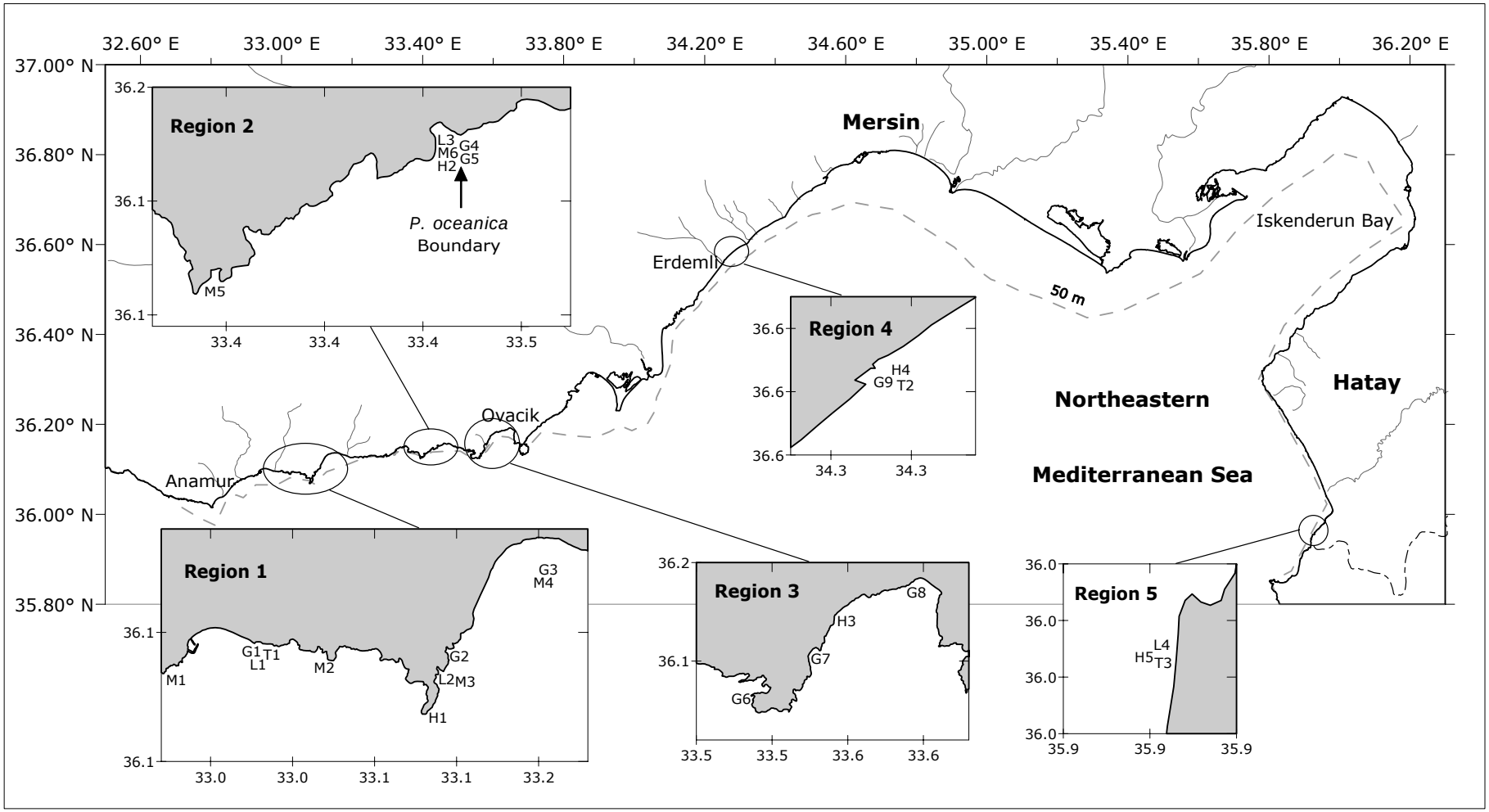


Figure 2.1 The study area; the five regions were mapped detailed to show the stations.

Table 2.1 List of data collection for this study.

*) transect line from depth of 30m to 10m; †) for details see section 2.5.

REGION	STATION CODE / DEPTH	LATITUDE	LONGITUDE	DESCRIPTOR TYPE	DATE
1	H1 / 10m	N36°04.203'	E33°04.901'	Temperature Logger	08.2005 – 07.2006
	H1 / 15m	N36°04.209'	E33°04.921'	Temperature Logger	08.2005 – 12.2006
	G1 / 5m	N36°05.821'	E32°58.667'	Sedimentological and geochemical analysis	22.12.2005
	G2 / 10m	N36°05.671'	E33°05.718'	Sedimentological and geochemical analysis	22.12.2005
	G3 / 30m	N36°07.143'	E33°09.060'	Sedimentological and geochemical analysis	13.12.2005
	M1 *)	N36°04.960'	E32°55.860'	Meadow parameters	09.05.2005
	M2 *)	N36°05.130'	E33°01.470'	Meadow parameters	24.06.2005
	M3 *)	N36°05.050'	E33°05.370'	Meadow parameters	22.12.2005
	M4 *)	N36°06.970'	E33°09.180'	Meadow parameters	24.06.2005
	L1 / 15M	N36°05.640'	E32°58.540'	Lepidochronological analysis	17.10.2006
	L2 / 10m	N36°05.120'	E33°05.390'	Lepidochronological analysis	22.12.2005
	L2 / 15m	N36°05.110'	E33°05.320'	Lepidochronological analysis	22.12.2005
	T1 †)	N36°05.760'	E32°58.667'	Transplantation	12.2004 – 10. 2006
2	H2 / 10m	N36°09.246'	E33°26.716'	Temperature Logger	08.2005 – 12.2006
	H2 / 15m	N36°09.197'	E33°26.801'	Temperature Logger	08.2005 – 12.2006
	G4 / 10m	N36°09.246'	E33°26.716'	Sedimentological and geochemical analysis	13.11.2005 14.12.2006
	G5 / 19m	N36°09.161'	E33°26.696'	Sedimentological and geochemical analysis	21.12.2005 14.12.2006
	M5 *)	N36°07.760'	E33°23.850'	Meadow parameters	24.12.2005
	M6 *)	N36°09.130'	E33°26.660'	Meadow parameters	29.09.2004
	L3 / 10m	N36°09.250'	E33°26.700'	Lepidochronological analysis	24.01.2006
	L3 / 15m	N36°09.210'	E33°26.790'	Lepidochronological analysis	24.01.2006
3	H3 / 5m	N36°10.499'	E33°35.479'	Temperature Logger	08.2005 – 05.2006

Table 2.1 continue

3	H3 / 10m	N36°10.500'	E33°35.530'	Temperature Logger	08. 2005 – 12.2006
	G6 / 22m	N36°07.723'	E33°32.073'	Sedimentological and geochemical analysis	21.12.2005 14.12.2006
	G7 / 10m	N36°09.335'	E33°34.678'	Sedimentological and geochemical analysis	24.12.2005 14.12.2006
	G8 / 15m	N36°11.264'	E33°38.478'	Sedimentological and geochemical analysis	13.11.2005 14.12.2006
4	H4 / 10m	N36°33.941'	E34°15.631'	Temperature Logger	08.2005 – 09.2005
	H4 / 15m	N36°33.870'	E34°15.717'	Temperature Logger	08.2005 – 11.2005
	G9 / 15m	N36°33.715'	E34°15.572'	Sedimentological and geochemical analysis	14.11.2005 20.12.2006
	T2 †)	N36°33.830'	E34°15.730'	Transplantation	12.2004 – 10.2006
5	H5 / 10m	N35°57.100'	E35°55.288'	Temperature Logger	08.2005 – 11.2006
	H5 / 15m	N35°57.100'	E35°55.268'	Temperature Logger	08.2005 – 11.2006
	L4 / 13m	N35°57.100'	E35°55.280'	Lepidochronological analysis	14.10.2006
	T3 †)	N35°57.105'	E35°55.283'	Transplantation	12.2004 – 10.2006

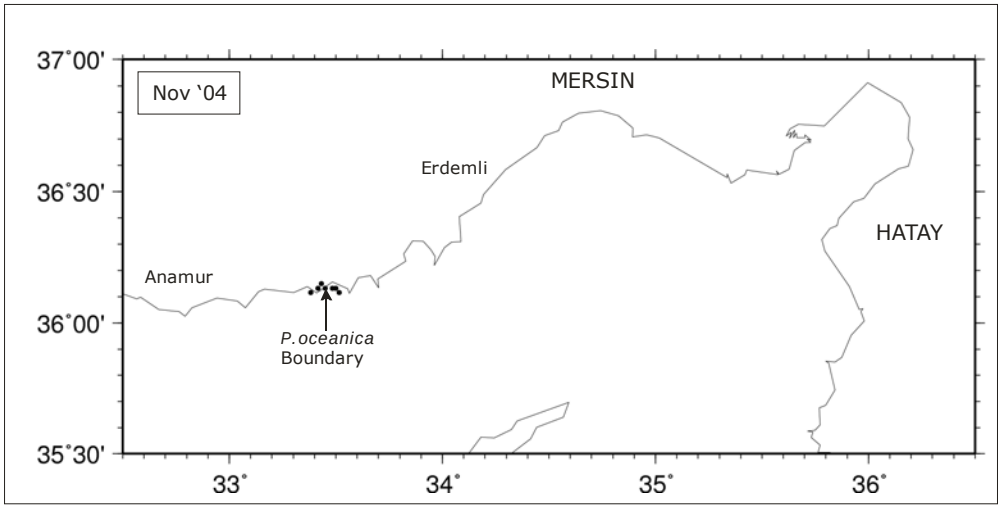


Figure 2.2 Stations for additional physical data collection (November 2004, $n_{[\text{number of stations}]}=7$).

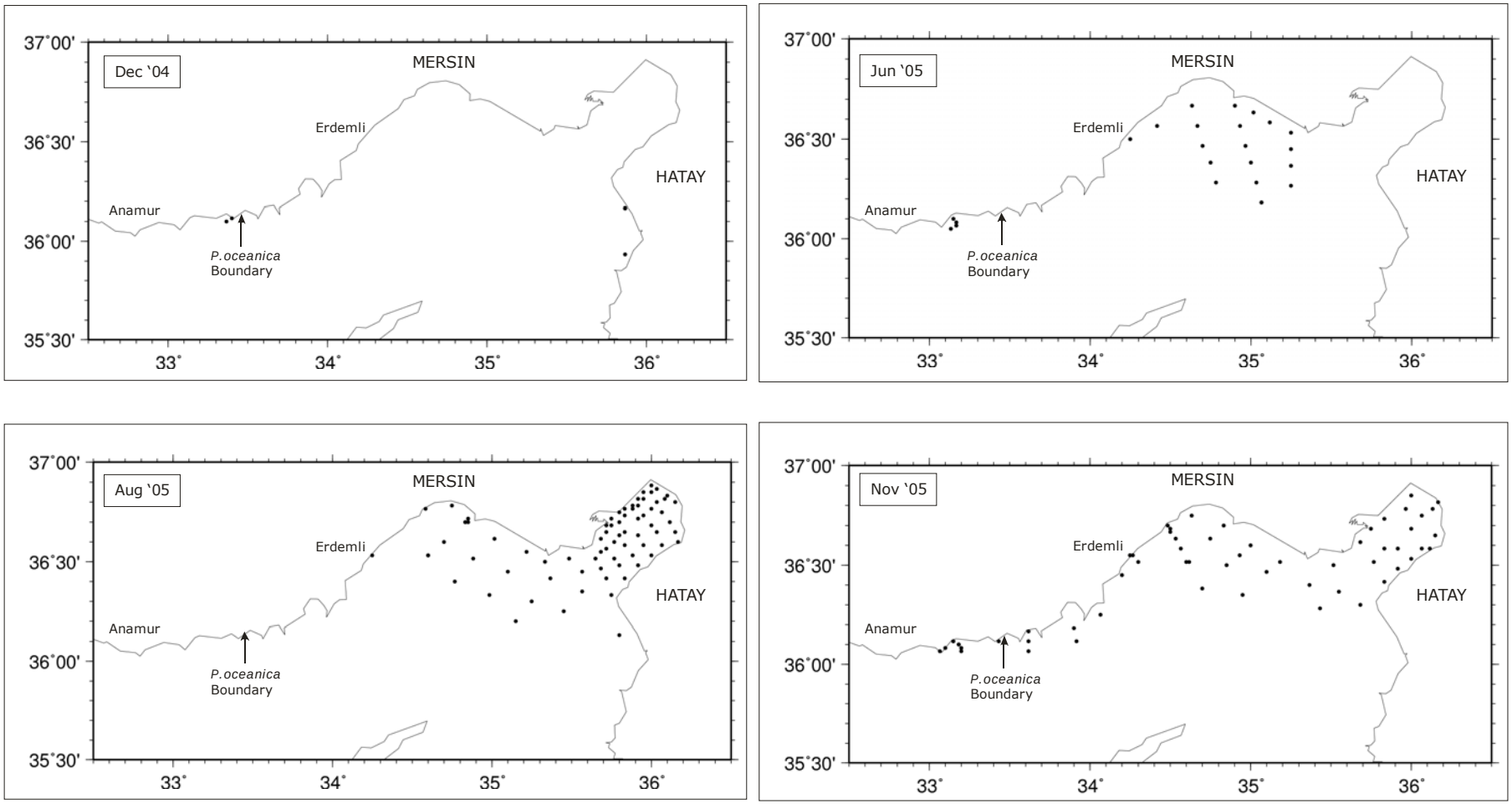


Figure 2.2 continue (December 2004, n=7; June 2005, n=29; August 2005, n=75; November 2005, n=65).

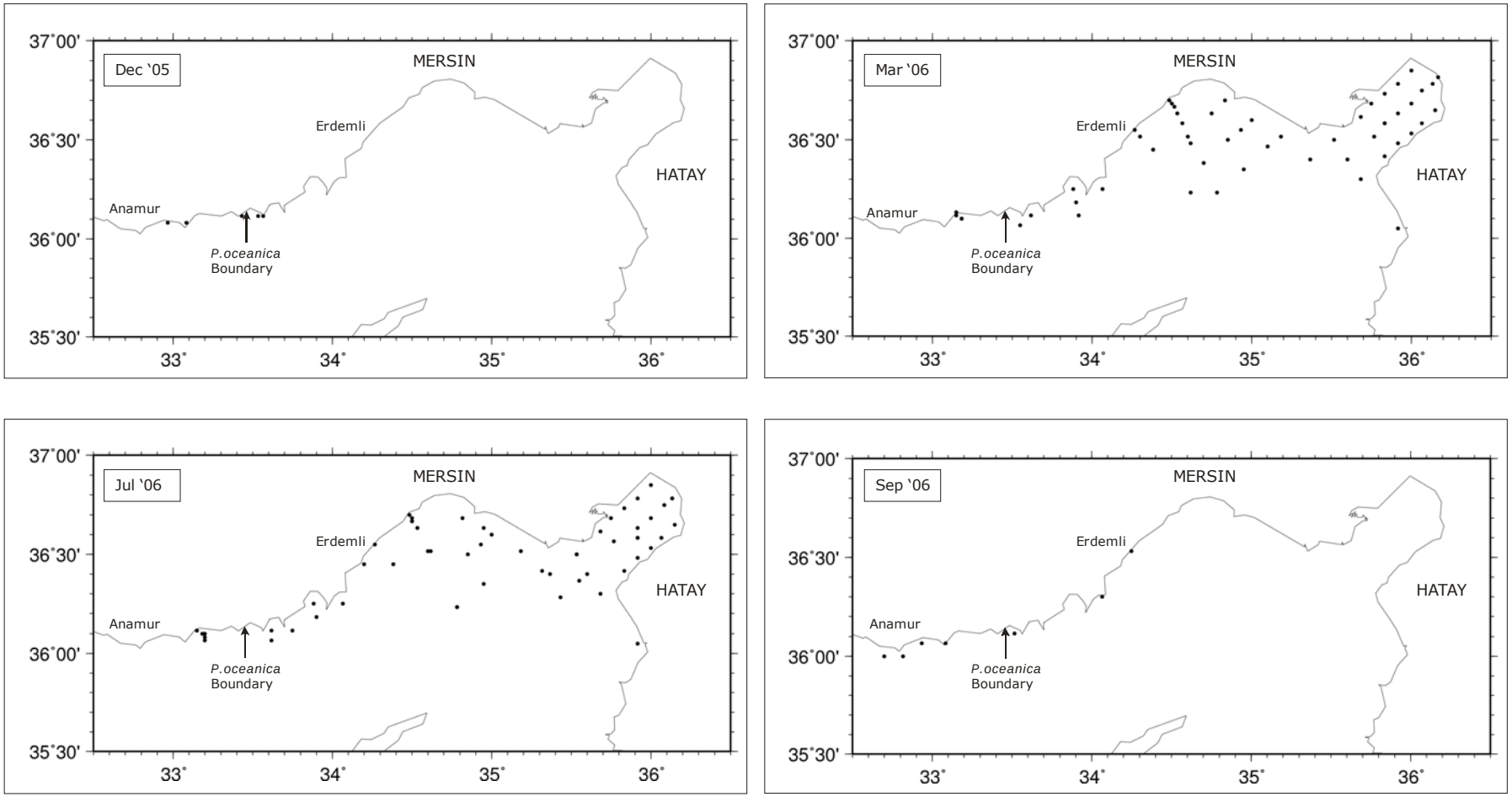


Figure 2.2 continue (December 2005, n=5; March 2006, n=56; July 2006, n=60; September 2006, n=7).

2.2 Abiotic descriptors

Abiotic descriptors included sea water temperature, salinity, light penetration and lastly the sediment analysis which was complemented by their geochemical analysis. The collection of parameters was categorized with their procedural details as follows;

2.2.1 Temperature

Temperature data was collected by three different methods. The vertical depth profile of sea water temperature was measured by means of SeaBird - SBE 9 Oceanographic CTD Profiler starting from winter 2004 to fall 2006 (Figure 2.2). These data was taken from the database of METU-IMS. Totally 9 cruises between these years were analyzed. Only the coastal stations which were shallower than 200 meter were considered (totally 311 stations).

For year-round measurement of sea water temperature at fixed depths with given time intervals, HOBO Pendant Temperature Data Loggers were used. These were waterproof one-channel loggers with an accuracy of ±0.47°C and a resolution of 0.10°C at 25°C. Totally 10 loggers (Table 2.1) were placed to 5 regions indicated on the Figure 2.1. The setup information of temperature loggers throughout the study period is given detailed in Table 2.2 .

The recording capacity of the loggers was limited to 1 month long if the setup interval time was 10 minutes. It was extended up to 3 and 6 months by increasing the interval time to 20 and 30 minutes, respectively. Due to the importance of high sea water temperatures for this study, the setup interval time was set to 10 minutes during warm seasons to differentiate the small fluctuations in temperature. On the other hand in cold seasons this interval was increased to 20 or 40 minutes according to the time lag between cruises.

In station H5, the loggers were relocated after the second setup to a next bay in the same region (Table 2.2, signs ◇ and ●). After the 3rd setup some of the loggers were missing, so they could not be reinstalled in 3 stations during the last setup periods (Table 2.2).

Table 2.2 Setup sites and dates of Temperature loggers.

For each setup interval time of recording is indicated in parenthesis;

◇ indicates new setup place and depth in H5,

● indicates new setup place and depth in H5 located next to the transplant frames.

LOCATION / DEPTH	1.SETUP (10min)	2.SETUP (10min)	3.SETUP (40min)	4.SETUP (20min)	5.SETUP (20min)
H1 - 10m	09/08/05 10/09/05	10/09/05 16/10/05 ----- 22/10/05 12/11/05	12/11/05 07/05/06	02/07/06 lost	-
H1 - 15m	09/08/05 10/09/05	10/09/05 16/10/05 ----- 22/10/05 12/11/05	12/11/05 07/05/06	02/07/06 22/09/06	22/09/06 13/12/06
H2 - 10m	08/08/05 09/09/05	09/09/05 23/10/05	13/11/05 08/05/06	02/07/06 23/09/06	23/09/06 14/12/06
H2 - 15m	08/08/05 09/09/05	09/09/05 23/10/05	13/11/05 08/05/06	02/07/06 23/09/06	23/09/06 14/12/06
H3 - 5m	08/08/05 09/09/05	09/09/05 23/10/05	09/11/05 04/05/06	-	-
H3 - 10m	08/08/05 09/09/05	09/09/05 23/10/05	09/11/05 04/05/06	02/07/06 lost	23/09/06 14/12/06
H4 - 10m	12/08/05 08/09/05	08/09/05 lost	18/01/05 ?	-	-
H4 - 15m	12/08/05 25/09/05	06/10/05 19/11/05	18/01/05 ?	-	-
H5 - 10m (◇;10m)	07/08/05 11/09/05	12/09/05 26/10/05	◇ 07/01/06 06/05/06	◇ 07/05/06 20/06/06 (10min)	◇ 09/09/06 12/11/06
H5 - 27m (●;13m)	07/08/05 11/09/05	12/09/05 lost	● 07/01/06 06/05/06	● 07/05/06 20/06/06 (10min)	● 09/09/06 12/11/06

Calculated from the records of temperature logger in station H1 at 10 meter depth, the mean temperature of the hottest day during the warmest season in 2005 (August, 23rd) was set as Maximum Tolerable Temperature Limit (MTTL) for *Posidonia oceanica* growth. The exposure time and percentages of each station to the Maximum Tolerable Temperature Limit value during the same warmest season was calculated.

Additionally, sea surface temperature (SST) obtained from satellite data were considered for comparison of the sub regions in Eastern Mediterranean Sea and the main regions around the Turkish coasts of Mediterranean Sea. The data was

gathered from "The Physical Oceanography Distributed Active Archive Center (PO.DAAC)" at the Jet Propulsion Laboratory/Caltech, which distributes several sea surface temperature products (SST) at different spatial and temporal resolutions (http://podaac.jpl.nasa.gov/sst). Within the scope of this study, the "NODC/RSMAS (version 5.0) and the NOAA/NASA (version 4.1) Pathfinder Advanced Very High Resolution Radiometer (AVHRR) SST" product was used. This was a high quality dataset derived from the NOAA polar-orbiting series of satellites that started with the NOAA-9 in 1985. This dataset represents a historical reprocessing of the entire AVHRR time series using consistent SST algorithms, improved satellite and inter-satellite calibration, quality control and cloud detection.

The NOAA/ NASA AVHRR Oceans Pathfinder sea surface temperature data were derived from the 5-channel AVHRR on board the NOAA -7, -9, -11, -14, -16 and -17 polar orbiting satellites. Daily, 8-day and monthly averaged data for both the ascending pass (daytime) and descending pass (nighttime) were available on equal-angle grids of 8192 pixels/360 degrees (nominally referred to as the 4km resolution, 4096 pixels/360 degrees (nominally referred to as the 9km resolution), 2048 pixels/360 degrees (nominally referred to as the 18km resolution), and 720 pixels/360 degrees (nominally referred to as the 54km resolution or 0.5 degree resolution).

In the present study monthly averaged AVHRR Oceans Pathfinder global 4km equal-angle all SST v5 (NOAA, NASA) data were extracted for 6 region in the Mediterranean Sea.

Sub regions in the north eastern Mediterranean Sea (Figure 2.1):

Overlapping with Region 1	35.50° N – 36.10° N / 33.00° E – 33.20° E
Overlapping with Region 2 and 3	35.50° N – 36.10° N / 33.20° E - 33.40° E
Overlapping with Region 5	35.55° N – 36.15° N / 35.30° E – 36.00° E

Main Regions along the Turkish coasts:

Aegean Sea (AS)	35.55° N – 40.43° N / 26.00° E – 29.00° E
Western Mediterranean Sea (WM)	35.55° N – 36.55° N / 29.00° E – 33.00° E
Eastern Mediterranean Sea (EM)	35.55° N – 37.00° N / 33.00° E – 36.15° E

The land area and cloud were masked by the use of quality flags.

2.2.2 Salinity and Light

The vertical salinity and light penetration profiles of sea water column was measured by SeaBird - SBE 9 Oceanographic CTD Profiler at the same stations as temperature profiles (Figure 2.2). Light measurements were taken by the Photosynthetically Active Radiation (PAR) sensor of CTD Profiler and only day time records were analyzed for light penetration depth calculations.

From this data set the upper 35 meter depth section of the vertical PAR/Irradiance profiles was used to calculate the light attenuation coefficient (K) in each station. This depth was the actual lower depth limit of *Posidonia oceanica* meadows in eastern Mediterranean Sea (Mihai, 1985). The K was defined by the Beer-Lambert exponential decay function (Short and Coles, 2001);

$$I_z = I_0 \, e^{-Kz} \qquad \text{(Eqn. 1)}$$

where I_z is the light measured at depth z
I_0 is the light measured just under the surface
K is the light attenuation coefficient
z is the depth

For each station by using the coefficient K, the depth, where the light penetration might be theoretically adequate for *Posidonia oceanica* growth, was calculated according to the formula by Duarte (1991);

$$\log Z_c \text{ (m)} = 0{,}26 - 1{,}07 \log K \text{ (m}^{-1}\text{)} \qquad \text{(Eqn. 2)}$$

where Z_c is the sea grass depth limit,
K is the light attenuation underwater.

2.2.3 Sedimentological and Geochemical analysis

Sediment samples were taken by using Van Veen grab in winter of 2005 and 2006 at 9 different sites for sedimentological and geochemical analyses (Figure 2.1 and Table 2.1). The grain size analysis was performed by the use of wet sieving and pipetting techniques according to the standard procedure outlined by Folk (1974).

In wet sieving analysis, approximately 50 g of each sample was oven dried at 60°C for 24 hours and weighted. They were washed with distilled water until to get rid of salt and dissolved organic matter. Then they were wet-sieved through 63 µm mesh size. The retained course material on the sieve was again oven dried at 60°C 24 hours long for further analysis by the dry sieving method through 2 mm mesh size.

The mud material that passed through 63 µm mesh size was further fractioned by pipette technique as follows; all mud collected from sieving was transferred to 1 liter measuring cylinder and filled with distilled water until to the top of column. After 12 hours settlement time the column was stirred with brass stirrer for 1 min. With the use of timing device 20 ml sample was taken at 20 cm depth from the column after 20 sec. This first withdrawal represented total mud (silt and clay) finer than 63 µm. After 2 hrs 3 min a second pipetting with same amount from 10 cm depth was repeated. This portion consisted of only clay material. All 20 ml samples were completed to 50 ml with distilled water and than oven dried for 24 hours at 60°C. After recording the dry weight of samples the total weight and percentage of silt and clay fractions were calculated as follows:

Wt. of mud (g) = 50 x pipette sample wt. of mud (Eqn. 3)

Wt. of clay (g) = 50 x pipette sample wt. of clay (Eqn. 4)

Silt % = (wt. of mud – wt. of clay) / (wt. of course particle + wt. of mud)

(Eqn. 5)

Clay % = wt. of clay / (wt. of course particle + wt. of mud) (Eqn. 6)

At the end sediments were separated into four different size fractions; gravel (>2 mm), sand (2 to 0.063 mm), silt (63 to 2 µm) and clay (<2 µm) (Folk, 1974).

In geochemical analysis, approximately 0.3 g of each sample was used to determine $CaCO_3$ content in the sediments. For that purpose the dried samples were grounded by using agath mortar and pestle down to a grain size less than 63 µm in diameter. Than they were mixed with 10% HCL acid for the below reaction to take place;

$$CaCO_3 + 2\ HCl \longleftrightarrow CaCl_2 + CO_2 + H_2O \qquad \text{(Eqn. 7)}$$

The volume of CO_2, produced due to reaction of excess HCL with sediment, was measured by a gasometer system. This was designed by Ediger (1991) based on the "Scheibler Calcimeter" (Müller, 1967). The height of the water in column, that rose up due to the barometric pressure was converted to the percentage of $CaCO_3$ in the samples via calibration curves. Beforehand the system was calibrated with standard samples for each experiment day in order to eliminate the differences in the laboratory conditions.

2.3 Structural descriptors

For the detection of geographical distribution boundary and depth limit typology of the *Posidonia oceanica* meadows in North Eastern Levant Sea as referred by Gücü and Gücü (2002) (Figure 2.1, Region 2), the study area starting from Taşucu (33° 53′ E) until Anamur (32° 50′ E) was searched by free diving and SCUBA diving methods during the cruise in September 2004.

During the same cruise, the northeastern boundary of *Posidonia oceanica* meadows (Figure 2.1) in Turgutlar Bay (N 36° 09.197′, E 33° 26.801′) was marked by cement blocks placed at 6 different depths along the deeper and eastern edge of the last patches to monitor the progression/regression of the boundary meadow (Figure 2.3). Some of the blocks were found overturned in the control and therefore replaced with new ones in November 2005. They were controlled regularly during the following cruises.

In addition to limit typologies, meadow density and fragmentation were measured at 6 stations (Table 2.1). The meadow density was determined by counting the number of living shoots per surface area unit with the use of 25x25 cm^2 quadrate (Figure 2.4). Starting from the deepest point of the meadow, 3 replica was done in every 5 meter depth interval until the shallowest limit in shoreline. The classification of *Posidonia oceanica* meadow types was determined according to Pergent *et. al.*. (1995, c.f. Buia *et. al.*, 2004). Also the length of the longest leaf was measured in each quadrate for 7 shoots. The percentage of the fragmentation in *Posidonia oceanica* meadows was estimated visually with a rope along a 10m transects line.

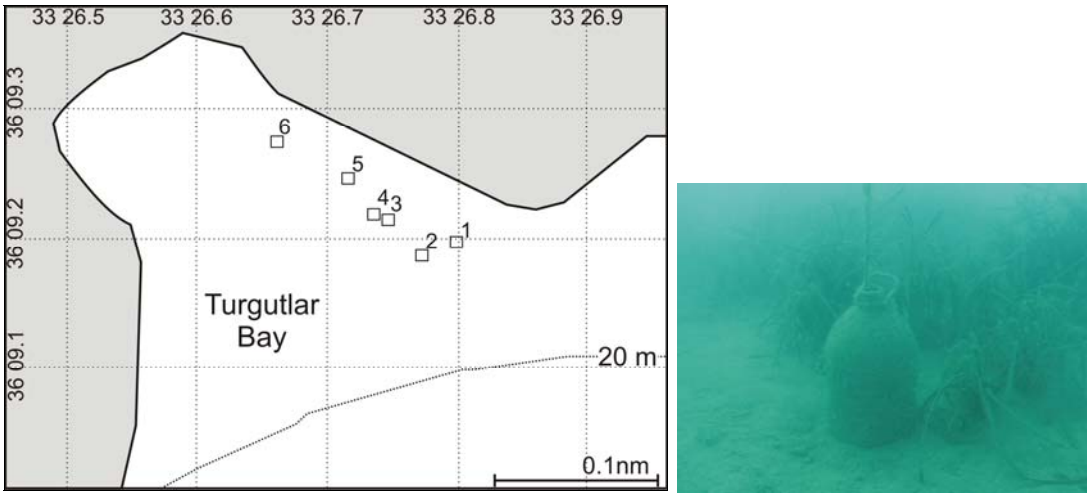


Figure 2.3 Sketch of boundary *Posidonia oceanica* meadow in Turgutlar Bay (Station M6, Figure 2.1), marked with cement blocks.

Depth of Blocks: 1- 15 m; 2- 17.2 m; 3- 16.8 m; 4- 16.2 m; 5- 10 m; 6- 5 m.

Figure 2.4 Measurement of meadow parameters.

2.4 Functional descriptors

Growth and primary production rates were estimated with the techniques "lepidochronology" and "phenology" described by Pergent (1991). For this purpose 20 shoots of *Posidonia oceanica* (Mayot *et. al.*, 2005) were collected from 2 depths at 2 stations (L2 and L3, Figure 2.1) and from 1 depth at 1 station (L1, Figure 2.1), all occupied by natural meadows (Table 2.1). The same techniques were applied to monitor the response of transplants after 1 year.

However, only 7 *Posidonia oceanica* cuttings were collected from transplantation site (L4, 13m) in order not to decrease the shoot density of transplanted frame (Figure 2.1, Region 5).

Lepidochronological analysis; For each shoot dead sheaths were detached and ordered from the older (near to base) to the more recent sheaths (near to leaves) (Figure 2.5). The thicknesses of the sheaths were measured with a hand micrometer (accuracy of 10µm) from 1 cm above the sheath base. The time scale between two minimum thicknesses was called one lepidochronological year. So each time a minimum thickness was encountered, it indicated the start of a new lepidochronological year. To harmonize the time scale with periodic cycling of sheath thicknesses, the sheaths were enumerated starting from the recent one to the older one (Figure 2.5 A, e.g. "year in progress" corresponds to year of sampling). Then the sheath thickness was plotted against the ranking number in reverse order in order to give the insight of lepidochronological cycles from past to present years (Figure 2.5 B).

If any flower stalk and prophyll was found between the sheaths (Figure 2.5 C), their place was noted and given an order number like each sheath in the lepidochronological cycle. It was differentiated from sheaths by the presence of a middle vein (Figure 2.5 D) and trapezoidal base (Pergent and Pergent-Martini, 1990). The mean leaf number produced per shoot per year, which was defined as leaf formation rate, was averaged through the number of sheaths according to each lepidochronological year.

For lepidochronological production estimates, the internodal distance of each rhizome segment corresponding to one lepidochronological year (from one minimum thickness to other minimum thickness) was measured micro-metrically under microscope. This was given as rhizome production in length (mm/shoot/year). All segments were then oven dried at 60°C for 48 hours until constant weight and weighted for rhizome production in weight (mg dry wt/shoot/year).

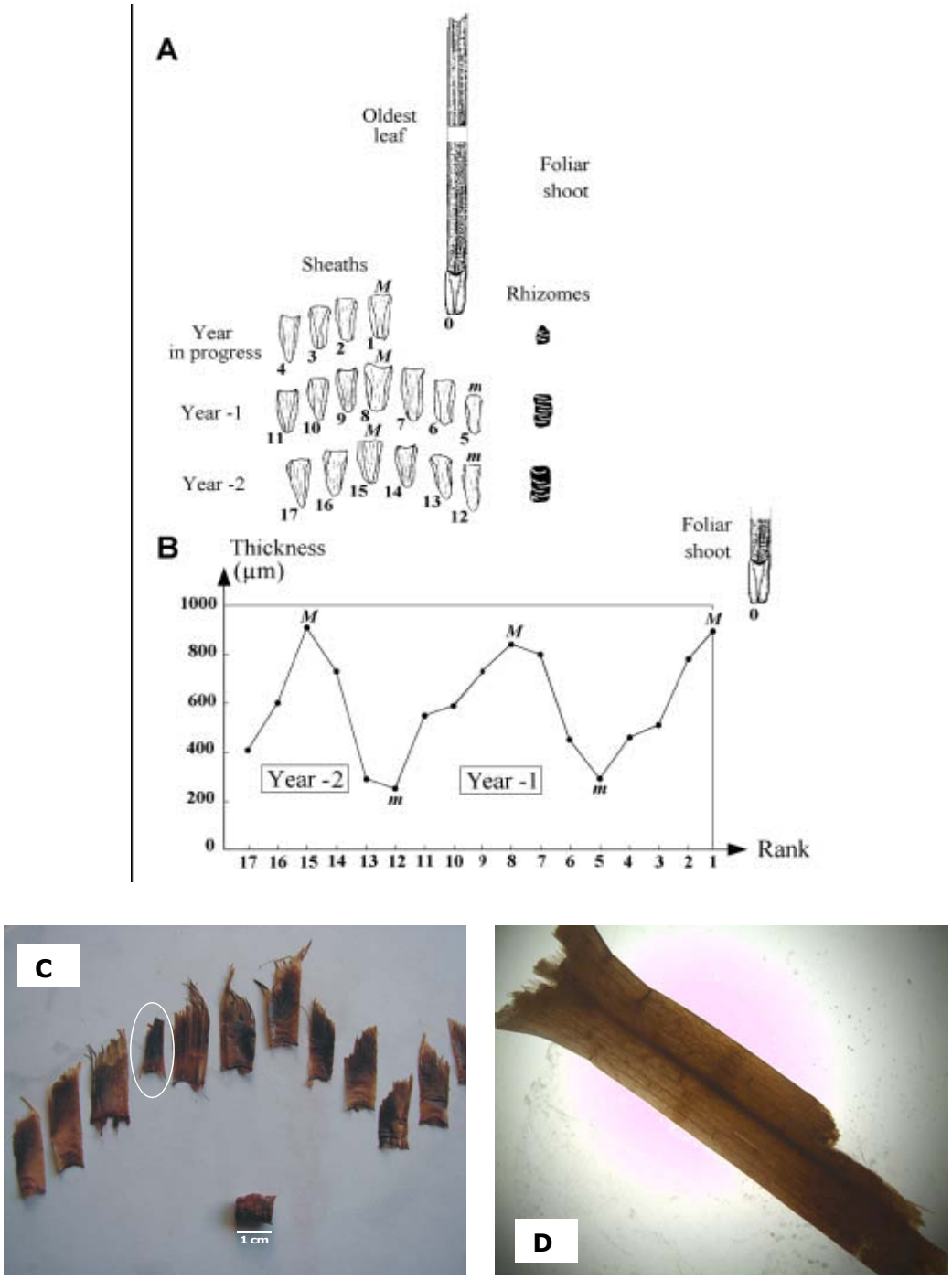


Figure 2.5 Dissection of *Posidonia* shoot using the lepidochronological technique (A) and evolution of sheath thickness according to the insertion rank (B) (from Pergent *et. al.*, 1997).

(C) Photography of lepidochronological analysis (white circle indicates the flower stalk).

(D) Detailed microscopic photography of flower stalk (magnification at 10X).

'M' in (B) sheath of maximum thickness; "m" sheath of minimum thickness

Modeling of lepidochronological cycles and SST of the sub regions; The results of lepidochronology related to sheath thickness were analyzed through nonlinear regression. A sinusoidal function was fitted to the observed cyclic variations in sheath thicknesses. The differences in the nonlinear regression parameters of 6 stations were compared. The same function was applied to monthly or yearly temperature cycles.

$$y = A \sin(\omega x - \Phi) + B \qquad \text{(Eqn. 8)}$$

where y is the sheath thickness

x is the lepidochronological time

A is the amplitude of the sinusoidal oscillation;

(thickest sheath – thinnest sheath) / 2

ω is depended on period (T) and defined by the formula;

$\omega = (2\pi / T)$, where T = 1 lepidochronological year, therefore

$\omega = 2\pi$

Φ is the horizontal shift in time

B is the vertical shift in thickness defined by the formula;

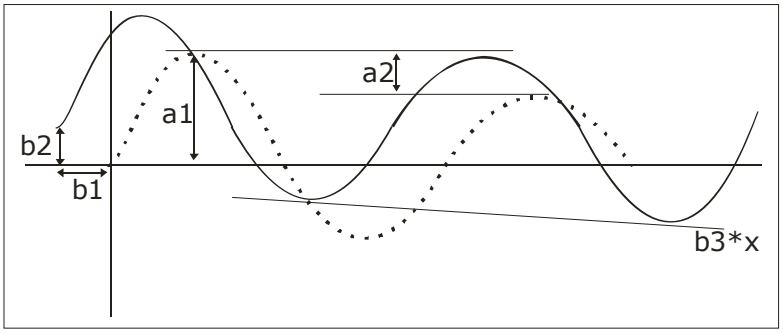
(largest data value + smallest data value) / 2

The procedure for the process was as follows; a scatter diagram of the data, treating lepidochronological time as the independent variable, was drawn. Then a sinusoidal function that fits the data was graphed on the scatter diagram. Through the program STATISTICA 6.0, the sinusoidal function of best fit was estimated. In this study, the nonlinear estimation procedures of this program were used for this purpose. The parameters for the nonlinear regression were estimated by using the least-squares criterion with the efficient Levenberg-Marquardt algorithm.

For the best fit three parameters of the basic sinusoidal function form was modified considering their changes with respect to x. Thus the amplitude (A), vertical shift (B) and horizontal shift (Φ) were related to lepidochronological time (x) as follows:

$$y = (|a1| + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x)) \qquad \text{(Eqn. 9)}$$

where modifications can be represented as follows:



The parameters a1, a2, b1 and b3 (Eqn. 9) were estimated using the same statistics program, whereas b2 was calculated by dividing the sum of maximum and minimum sheath thicknesses belonging to the first lepidochronological year in each shoot to 2, to fix the start of vertical distance with respect to most recent year.

The function was tested in 2 different ways for the same dataset. In the first run, all shoots in each station were put to the equation individually. Then the mean of all estimates for each parameter in each station were calculated, which was called as "mean model". Due to the nature of sinusoidal function, absolute value of 'a1' was forced in the model. The variance analysis of this model type was used to compare differences in the nonlinear regression parameters of 2 stations (L2 and L3) with their 2 different depths (10 and 15m). In the second run, all shoots in each station were considered as single data and put to the equation to obtain the, so called, "combined model".

Finally the same function was applied to SST data of the 3 sub regions to correlate their trend of the vertical shift (b3) with the one in lepidochronological cycles (b3) overlapping the same sub region.

Phenological analysis; For each shoot, the leaves were ranked in distichous order as it was done for sheaths in lepidochronology (Figure 2.6). The total length and width of each leaf were measured with a millimetric ruler. The width for each leaf was measured at two points; one was from 1 cm above the leaf base and the second measurement place corresponded to the middle of the leaf length. Afterwards by multiplying the leaf width with leaf length, the Leaf Area Index (LAI) was calculated for adult and intermediate leaves. For adult leaves, blades and sheaths were considered separately to differentiate between

photosynthetic leaf area index and general leaf area index, whereas these were equal to each other for intermediate leaves due to consisting of only blade part. For adult leaves beside the length of sheaths, their thicknesses were also considered.

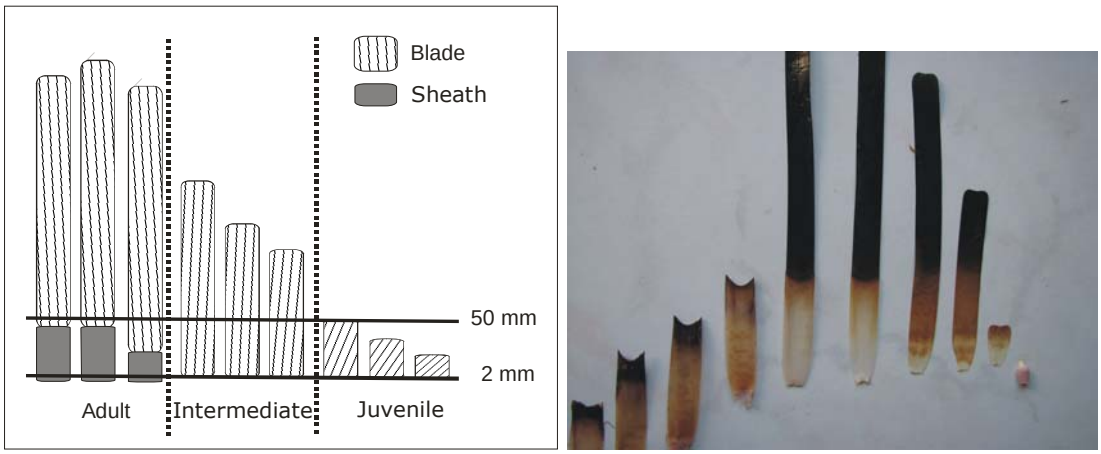


Figure 2.6 Phenological analysis.

Leaves are categorized in 3 classes after Giraud, 1977, (c.f. Larkum *et. al*., 2006). These are;

- Adult leaves (having sheaths longer than 2mm),
- Intermediate leaves (no sheaths) and
- Juvenile leaves (shorter than 50mm).

Additional production estimates were carried on through phenology. The oldest leaf with the order number 1 was scraped with a razor blade to remove epiphytes. Then these leaves, coming one from each shoot and being composed of blade + sheath, were oven dried at 70° for 48 hours until constant weight and weighted for primary production (mg dry wt/shoot) (Pergent *et. al*., 2004).

$$PI_{(mg\ dry\ wt\ /\ shoot)} = N_{(1/shoot)} \times (BL \text{ or } SL_{(cm)}) \times (BD \text{ or } SD_{(mg\ dry\ wt/cm)}) \quad \text{(Eqn. 10)}$$

where PI is the primary production

N is the mean number of leaves produced per year per shoot (=leaf formation rate; obtained from lepidochronological analysis)

BL is the mean length of blade (from adult leaves)

SL is the mean length of sheath (from adult leaves)

BD is the mean leaf tissue density of blade

SD is the mean leaf tissue density of sheath

For the determination of grazing pressure in natural meadows, the number of leaves per shoot grazed from the apex by herbivores was recorded during phenological analysis. This was called coefficient A and given in percentages per shoot.

2.5 Transplantation

For transplantation, *Posidonia oceanica* shoots were collected either by SCUBA or free diving. Random collection of orthotropic and plagiotropic shoots was made during the study period from 2 stations; in Turgutlar bay (L3, Figure 2.1) where the eastern most boundary of meadows along the southern coasts of Turkey is present (Gücü and Gücü, 2002) and in station L1 (Figure 2.1) which is classified as healthy meadows. Additionally some shoots from the by-catch of trawl surveys were used as cuttings to reduce the impacts on donor *Posidonia oceanica* meadows.

Collected *Posidonia oceanica* cuttings were stabilized to the bottom by the use of hand made frames. The edges of the frames were from iron and the inside area was gridded into 25 cm^2 squares with nylon ropes. The cuttings were attached to the grids with nylon cable ties in seawater (Figure 2.7).

Figure 2.7 Preparation of frames for transplantation (frame number F6).

Total of 21 frames with different coverage areas ranging from 0.49 to 2.25 m^2 were placed at 3 different stations in winter of 2004, in spring and autumn of 2005 and in spring of 2006 (Table 2.3). The size of the frames varied according to the collected and attached number of *Posidonia oceanica* cuttings.

Table 2.3 Details of transplantation experiment.

*) indicates cuttings from trawl by-catch.

FRAME #	COLLECTION LOCATION	COLLECTION DEPTH (m)	TRANSPLANT DATE	TRANSPLANT LOCATION	TRANSPLANT DEPTH (m)	SUBSTRATE TYPE	APPROXIMATE # OF CUTTINGS	SIZE OF GRID (m²)
F1	M5	27-30	09.12.04	T3	19,2	Sand with *Cymodocea sp.*	422	1*1
F2	M2 *	21-27	09.12.04	T3	19,3	Sand with *Cymodocea sp.*	191	1*1
F3	M6	15-17	27.05.05	T2	14,6	Silt	158	1,5*1,5
F4	M6 *		27.05.05	T2	14,3	Silt	337	1,5*1,5
F5	M2	3-4	01.06.05	T2	13,7	Silt	200	0,7*0,7
F6	M1 *	24-26	11.07.05	T2	14,6	Silt	270	1,5*1,5
F7	M2		03.08.05	T2	1,5	Silt		1,5*1,5
F8	M2	3,5	10.09.05	T1	6	Sand with *Posidonia oceanica*	400	1,5*1,5
F9	M2	3,5	12.09.05	T3	13	Sand with *Cymodocea sp.*	370	1,5*1,5
F10	M2	3,5	14.10.05	T2	10	Silt	500	1,5*1,5
F11	M6	10-15	09.02.06	T2	7,5	silt	290	1,0*0,8
F12-F22	M2	3	07.05.06	T3	16	Sand with *Cymodocea sp.*		0,7*0,7

The transplantation sites and depths were chosen according to the suitability of substrate type and wave action. The substrates settled with pioneer seagrass species were preferred, e.g. the presence of *Cymodocea nodosa* in station T3 (Figure 2.1). Except the frame F7, which was located inside the harbor of the institute to visualize the grazing activity, all cuttings were transplanted to deeper than 5 meter to reduce the wave destruction.

Grazing; For the determination of *in-situ* grazing pressure on transplanted cuttings an underwater camera system with a monitor was set in the institute's harbor from February to April in 2006 (Figure 2.8). With 2 hour intervals *Posidonia oceanica* cuttings were observed and during the presence of potential herbivores the behavior was recorded with a video.

Figure 2.8 Monitoring system in the institute's harbor.

This system was accompanied by experimental aquarium setups which were filled with seawater from the harbor. The water was filtered continuously and the temperature was kept constant by the heaters. Two aquariums with different bottom vegetation types were designed for observation of the behavior of potential grazer Indo-Pacific conch, *Conomurex persicus* with 2 hours interval during the same period. The first aquarium consisted of only *Posidonia oceanica* cuttings fixed to a sandy bottom without any other marine organisms. In the second one the substrate was diversified by some fish and gastropod species, e.g. *Symphodus spp*., additional to the *Posidonia oceanica* cuttings.

3. RESULTS

The outcomes of this study will be analyzed with respect to the descriptors ordered in previous chapter. The state of *Posidonia oceanica* meadows and the differences of descriptors at each station and region will be compared.

3.1 Abiotic descriptors

In this section, to compare the numerous vertical sea water profiles the study area was divided into 2 zones (Figure 2.2). The non-*P. oceanica* zone extended eastwards from the *Posidonia oceanica* boundary meadow at Turgutlar Bay (M6) to Syrian border, including the regions 3, 4 and 5 (Figure 2.1). On the other hand the *P. oceanica* zone, only for this study, was defined as the area between Turgutlar Bay and Anamur cape, including the regions 1 and 2. The results of the vertical profiles from CTD were explained only for the first 60 meter depth column. All other parameters were given for each station separately.

3.1.1 Temperature

On the overall, the sea water temperature of the study area ranged between 16 -21°C in cold seasons and between 18 – 30°C in warm seasons through the upper 60 meter depth column (Figure 3.1 to 3.7). A different pattern of vertical temperature change was observed according to seasons. During the cold seasons the profiles were constant through the vertical column (Figure 3.1) and no remarkable differences were noticed between the 2 zones defined. Contrarily in warm seasons the upper 15 meter depth column had higher temperatures than the rest of the column until 60 meter (Figure 3.2) and even the 2 regions differed in temperature. Especially in July and September 2006, the temperatures of the stations in non-*P. oceanica* zone were slightly higher than the ones in *P. oceanica* zone.

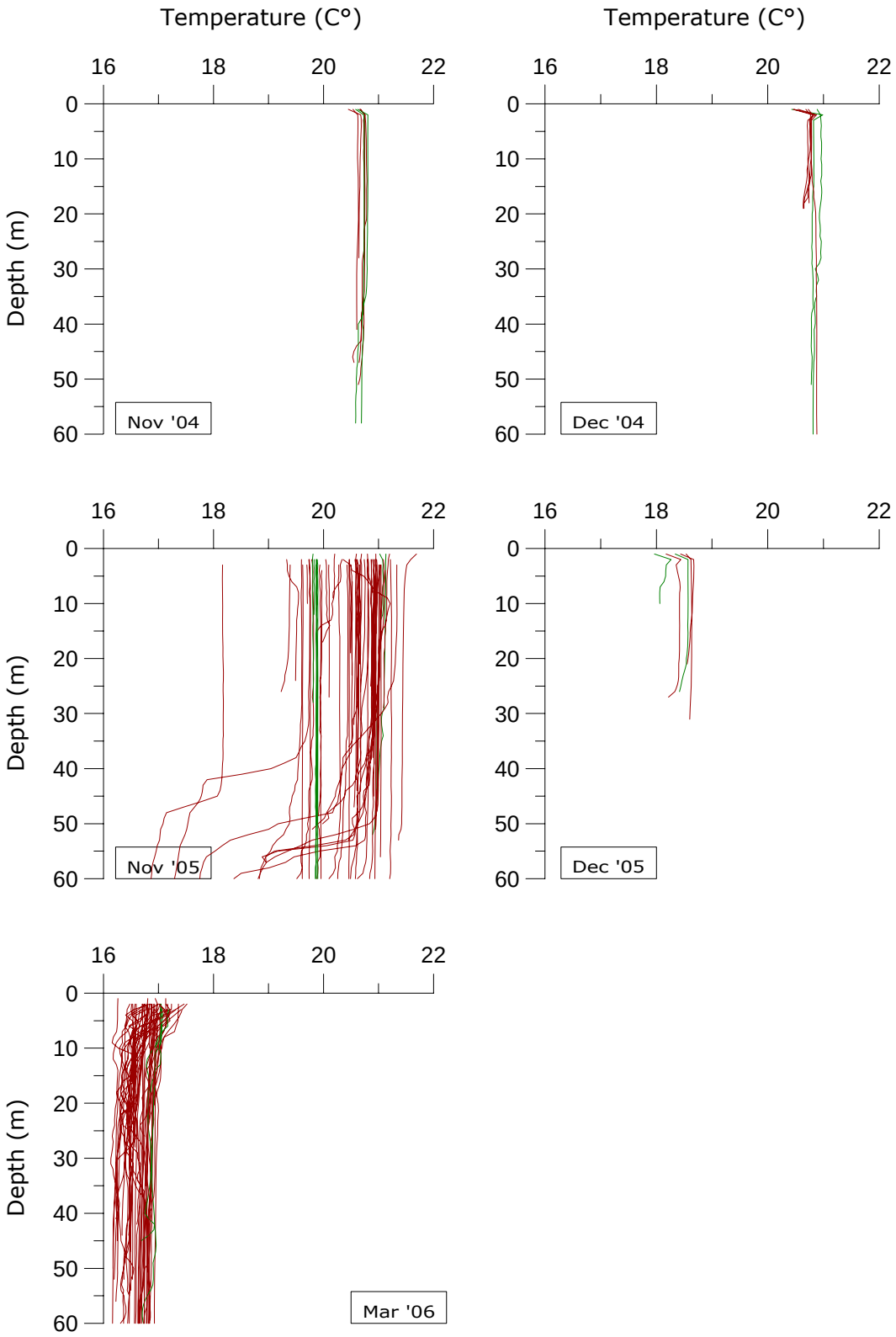


Figure 3.1 The vertical temperature profiles in cold seasons.

Red lines, stations in non-*P .oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

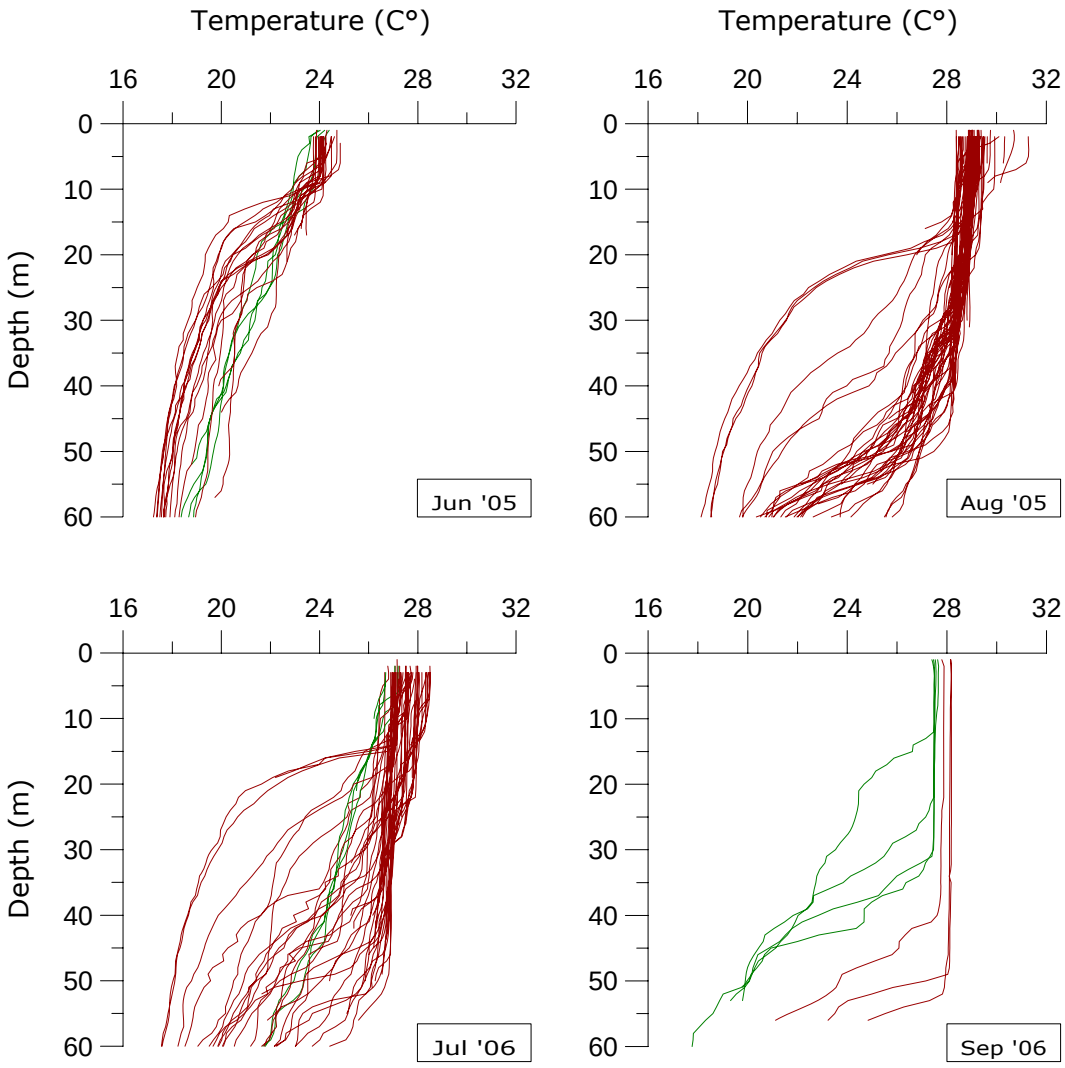


Figure 3.2 The vertical temperature profiles in warm seasons.

Red lines, stations in non-*P. oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

Additional to the differences in vertical seawater temperature profiles exemplified by the CTD profiles, the longitudinal differences and daily fluctuations of seawater temperature at fixed depths in infralittoral zone throughout the whole year were amplified by the temperature loggers (from Figure 3.3 to 3.7). Accordingly, in all stations the seawater temperature at 10 meter depth ranged between 29.5°C and 16°C starting from August 2005 until to December 2006. During this period the lowest temperatures were recorded in February and March 2006 and highest temperatures in the second half of Augusts 2005 and 2006.

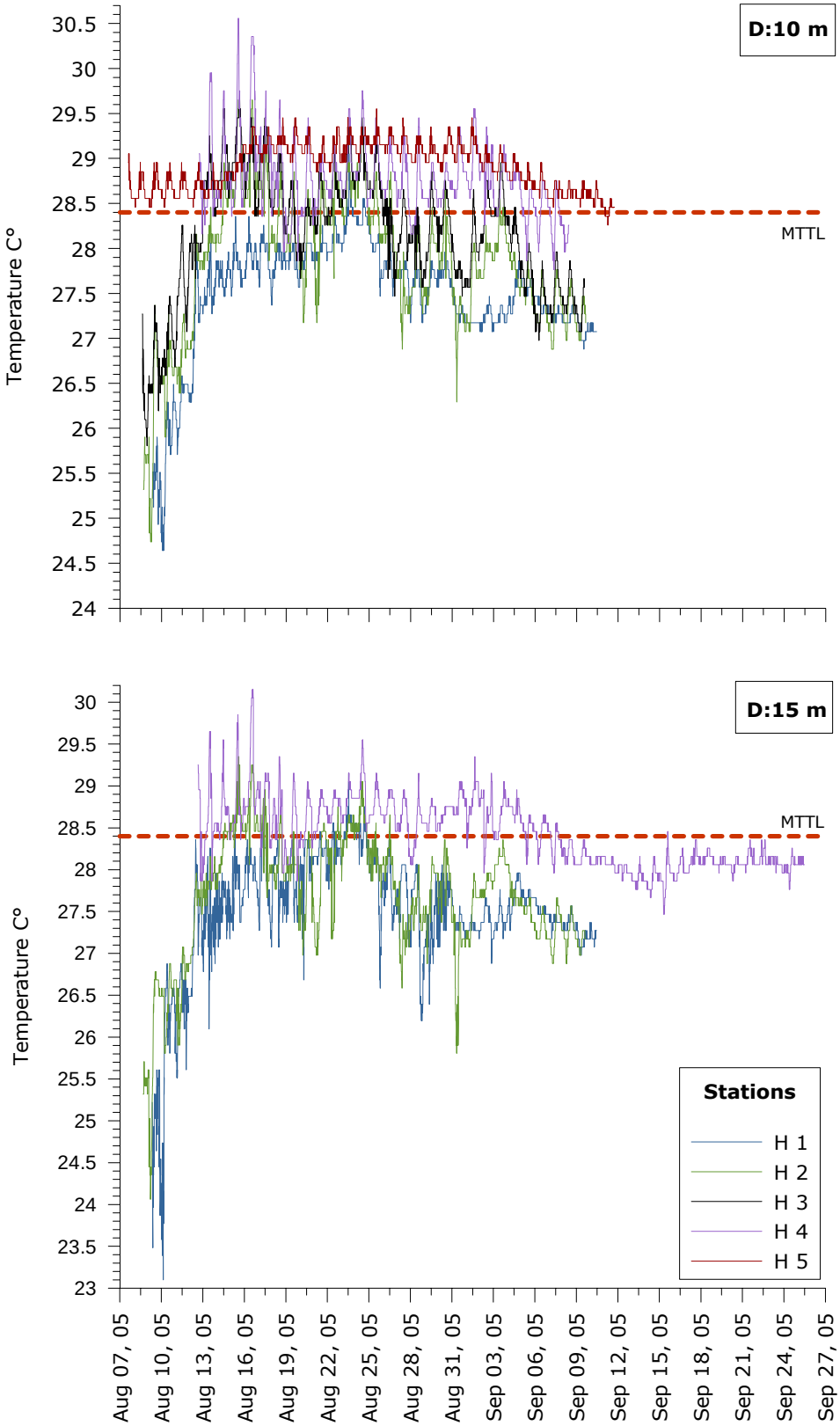


Figure 3.3 Continuous temperature records during Setup 1 period.

"D" indicates the depths of stations; red dotted line represents the Maximum Tolerable Temperature Limit (MTTL), which is 28.4°C (see Figure 3.8).

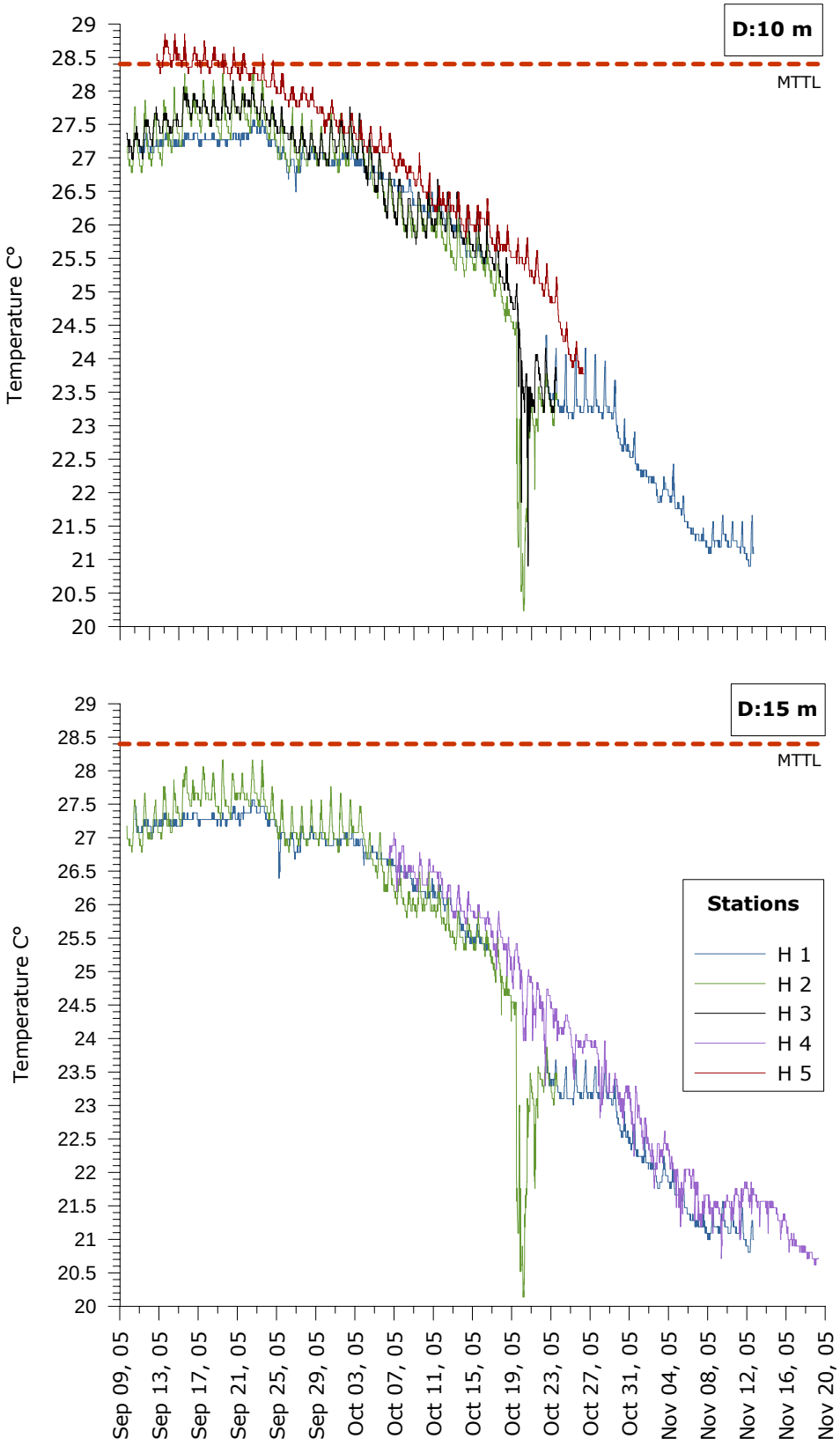


Figure 3.4 Continuous temperature records during Setup 2 period.

"D" indicates the depths of stations; red dotted line represents the Maximum Tolerable Temperature Limit (MTTL), which is 28.4°C (see Figure 3.8).

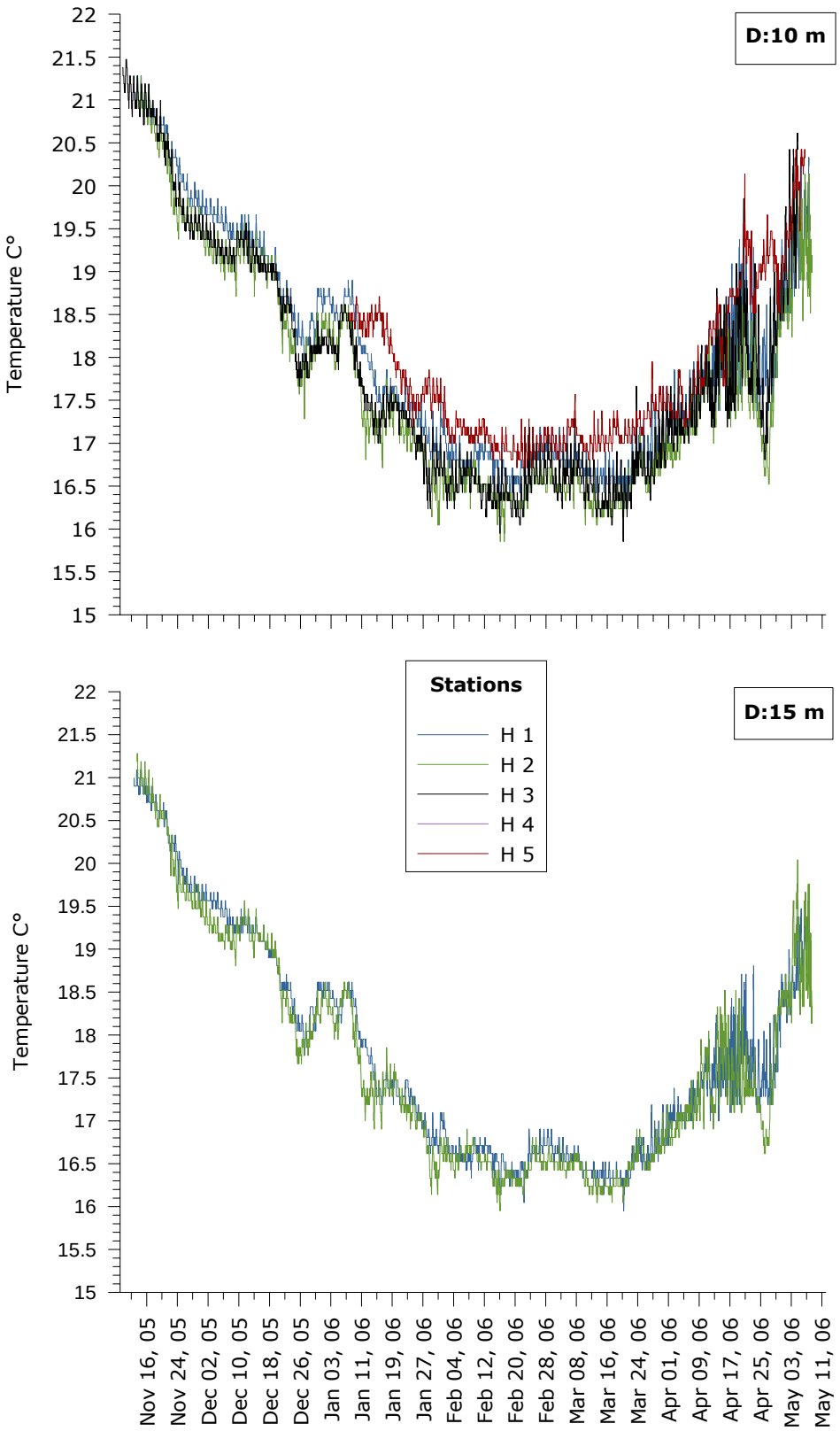


Figure 3.5 Continuous temperature records during Setup 3 period.

"D" indicates the depths of stations; red dotted line represents the Maximum Tolerable Temperature Limit (MTTL), which is 28.4°C (see Figure 3.8).

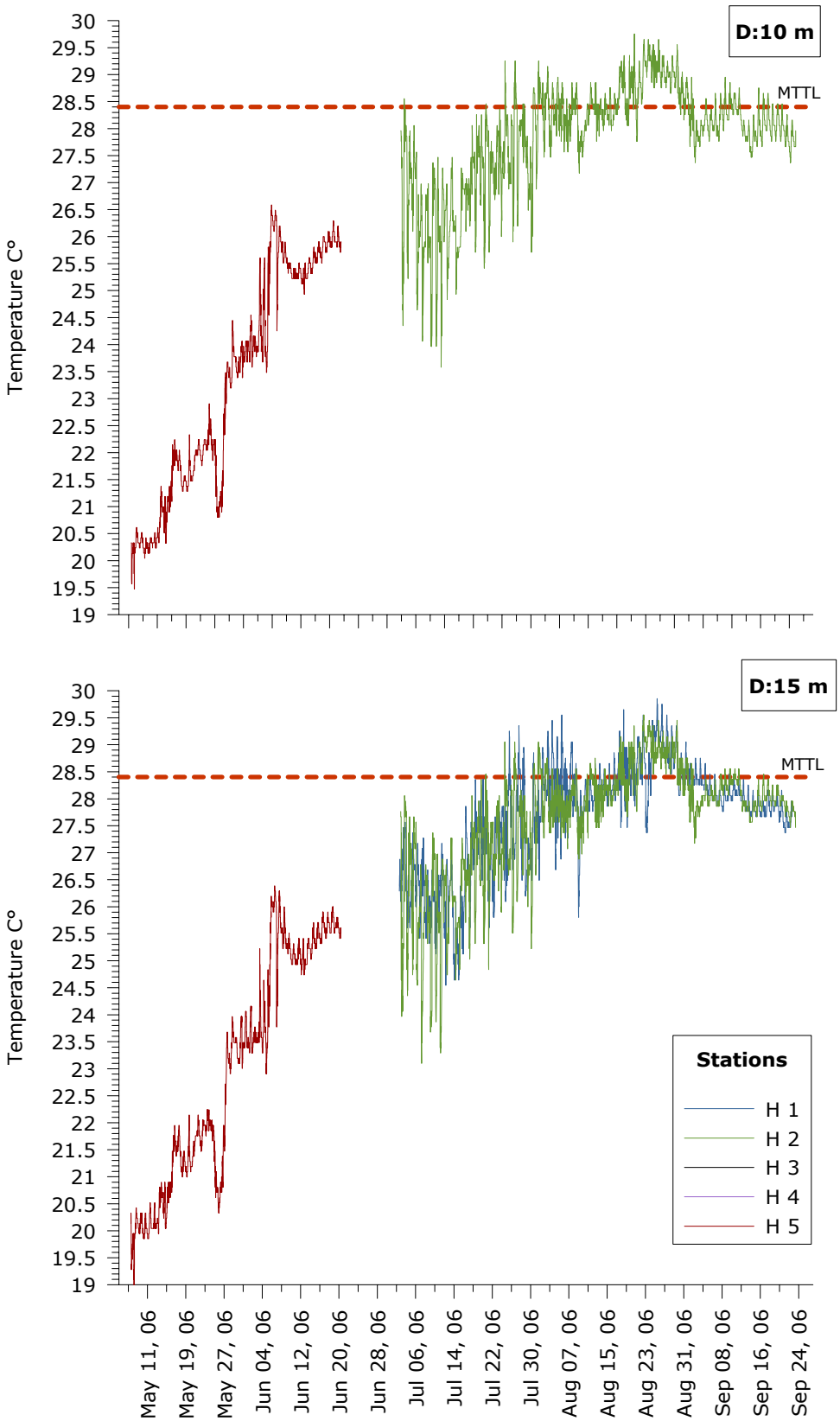


Figure 3.6 Continuous temperature records during Setup 4 period.

"D" indicates the depths of stations; red dotted line represents the Maximum Tolerable Temperature Limit (MTTL), which is 28.4°C (see Figure 3.8).

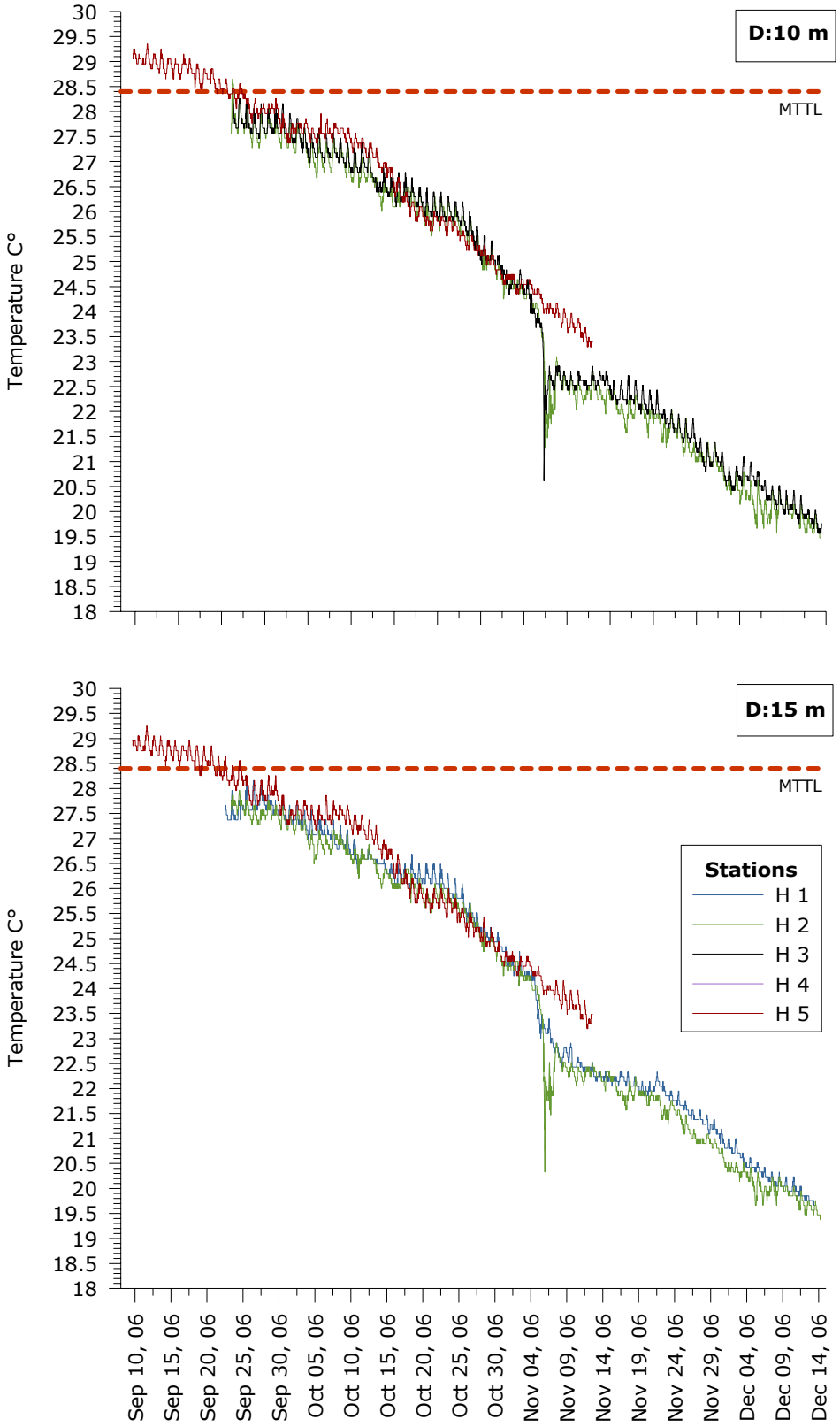


Figure 3.7 Continuous temperature records during Setup 5 period.

"D" indicates the depths of stations; red dotted line represents the Maximum Tolerable Temperature Limit (MTTL), which is 28.4°C (see Figure 3.8).

The general daily temperature fluctuations were higher during warm months (~1°C) whereas it was lessened in cold months (~0.5°C). Beside the smooth daily fluctuations, a dramatic temperature change of magnitude 3°C just in few days were observed at H5 in May 2006 and at H2-H3 in October of both 2005 and 2006, respectively (Figure 3.4, 3.6 and 3.7).

Though the similar patterns of temperature fluctuations in the whole study area, the comparison of the temperature values between the regions showed a general longitudinal increasing trend from western to eastern during all setup periods. The eastern most station H5 near to the Syrian border showed the highest temperatures during all setup periods. The western most station H1 had the relatively low temperatures during the warmest season in 2005 (Figure 3.3), but overlapped in other months with station H2 and H3 (Figure 3.4 to 3.7). The station H4 in front of the Institute in Erdemli had higher seawater temperatures than the first 3 stations during setup 1 and setup 2. Then recording at this station could not be continued because the loggers were lost due to commercial trawling activity in November 2005.

To clarify the significant differences between the most eastern and most western stations and to underline the importance of such distinction during the warm seasons the critical value was marked on the graphs of all setups in warm seasons (from Figure 3.3 to 3.7, except Figure 3.5). This value differentiating the non-*P. oceanica* zone (e.g. Region 5) from *P. oceanica* zone (e.g. Region 1) and defined as maximum tolerable temperature limit (MTTL) for *Posidonia oceanica* growth was found 28.4°C (Figure 3.8).

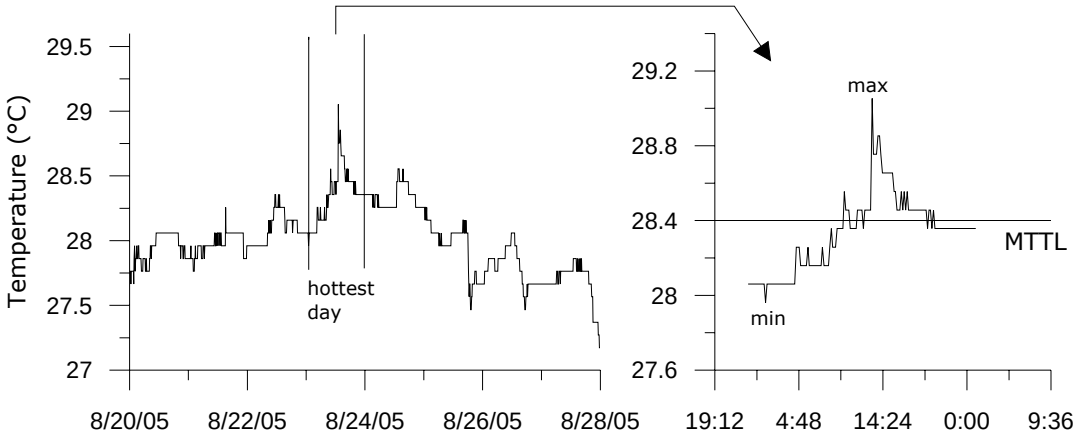


Figure 3.8 Calculation of maximum tolerable temperature limit (MTTL).

Daily (24h) mean temperature of the hottest day (23th Aug) in station H1 at 10 meter depth was 28,4°C (S.E.=0.02°C).

The exposure time to the maximum tolerable temperature limit varied in all stations during the period of setup 1 (Table 3.1). The eastern most station, H5 (Figure 2.1), was exposed higher temperatures than MTTL during the whole setup 1 period, while the western most station had lower percentage.

Table 3.1 Duration of exposure to maximum tolerable temperature limit during the period of setup 1.

STATIONS	TOTAL SAMPLING TIME (min)	TOTAL EXPOSURE TIME (min)	PERCENTAGE
H1, 10m	41380	1710	4.13
H1, 15m	46240	3580	7.74
H2, 10m	40250	12510	31.08
H2, 15m	46060	8820	19.15
H3, 5m	46060	24420	53.02
H3, 10m	40110	21700	54.10
H4, 10m	38480	35040	91.06
H4, 15m	63060	34060	54.01
H5, 10m	43180	43160	99.95
H5, 27m	50540	50540	100.00

Lastly the SST data, taken from NOAA satellites, were compared for the 3 sub regions in order to see the long term trends in these regions (Figure 3.9). From 1985 to 2005, the region 5 (Figure 3.9 A) was always warmer, having the higher yearly maximum, minimum and average temperatures while the first two regions (R1, R2-R3) coincided. Only in the last 7 years there was a disorder for the yearly maximum temperatures (Figure 3.9 A).

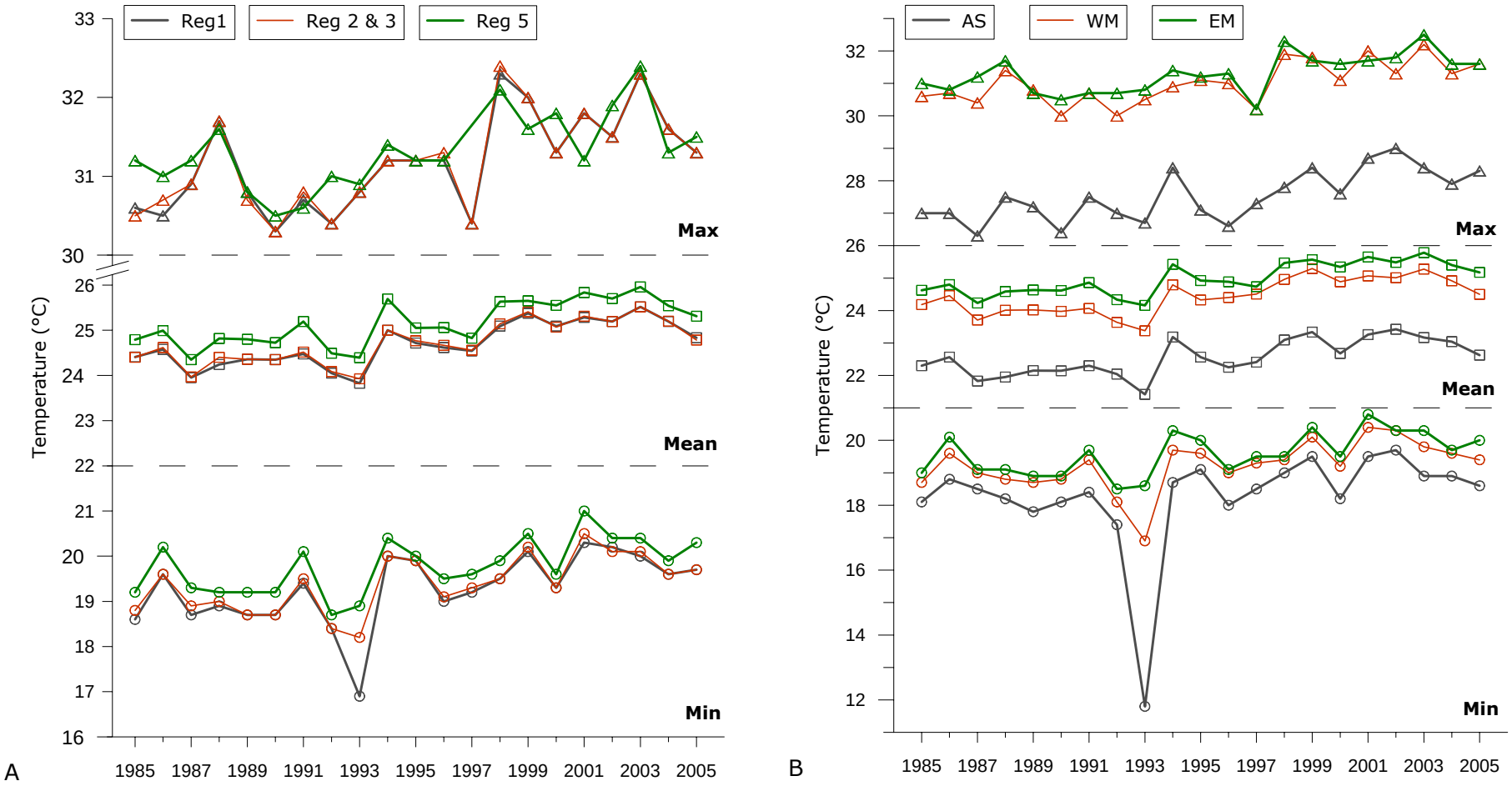


Figure 3.9 Sea Surface Temperatures (SST) for the sub regions (A) and main regions (B).

AS: Aegean Sea, WM: Western Mediterranean, EM: Eastern Mediterranean.

The larger scaled main areas were also compared along the Turkish coasts, where healthy meadows are present (Figure 3.9 B). The Aegean Sea differed from Mediterranean parts approximately 2°C in average temperature. This difference doubled in the maximum temperatures. Both Mediterranean regions being warmer than Aegean Sea varied among themselves, too. The eastern Mediterranean was ~0.5°C warmer than western Mediterranean in average. In 1993, an obvious abnormally was observed in minimum temperature of Aegean Sea. The temperature decreased to 12°C. The same decrease with a lesser magnitude (until to 17°C) was also observed in Western Mediterranean (Figure 3.9 A, min) and Region 1 (Figure 3.9 B, min). The concurrency of the main regions with sub regions appeared mainly in minimum temperatures. The Region 5 resembled the Eastern Mediterranean whereas the Region 1 resembled the characteristic of Western Mediterranean Sea.

3.1.2 Salinity and Light

Generally the vertical salinity profiles of the study area did not show an obvious difference between the non-*P. oceanica* zone and *P. oceanica* zone throughout the study period (Figure 3.10 and 3.10). During the cold periods of all the three years the vertical salinity values were nearly constant at 39.2 psu. In warm seasons the range of salinity increased up to 39.6 psu. Only in June 2005 and September 2006, the *P. oceanica* zone salinity profiles concentrated on a slightly lower salinity than the non-*P. oceanica* zone.

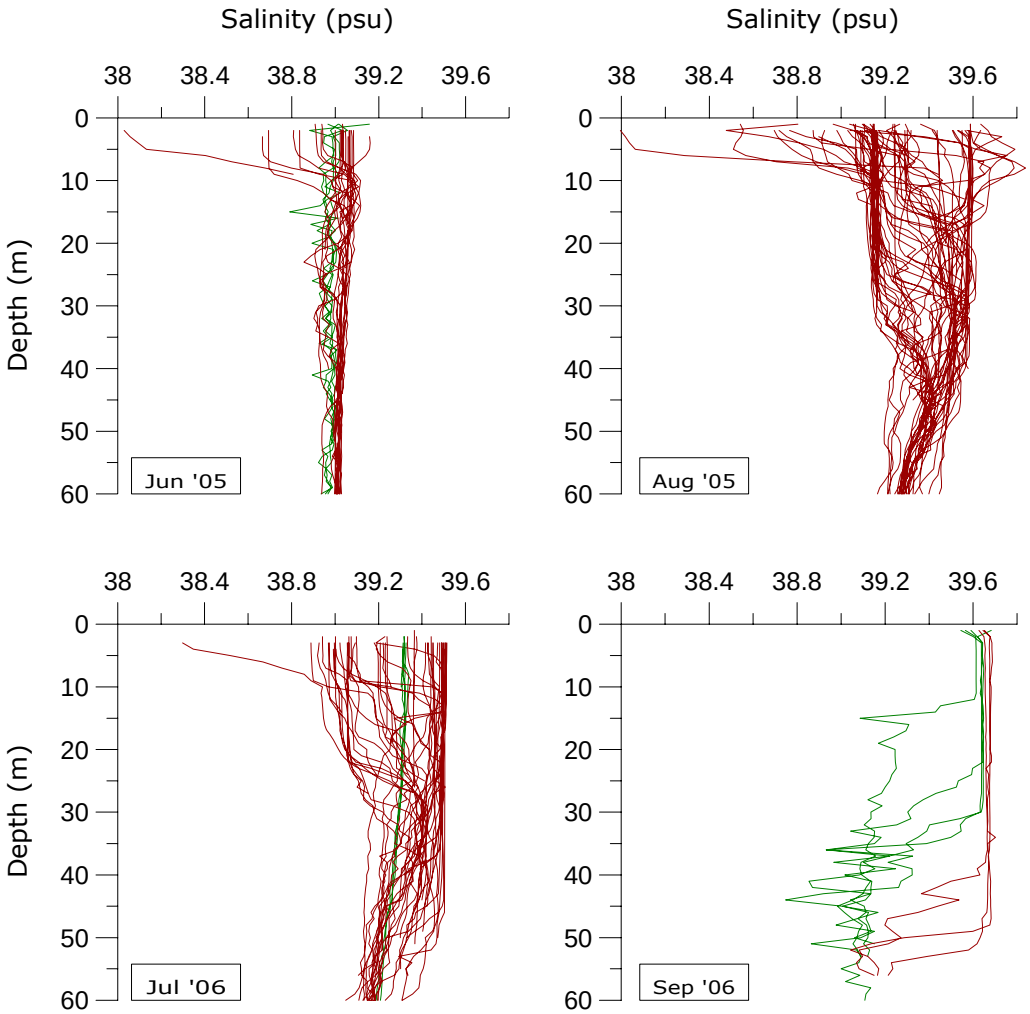


Figure 3.10 The vertical salinity profiles in warm seasons.

Red lines, stations in non-*P. oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

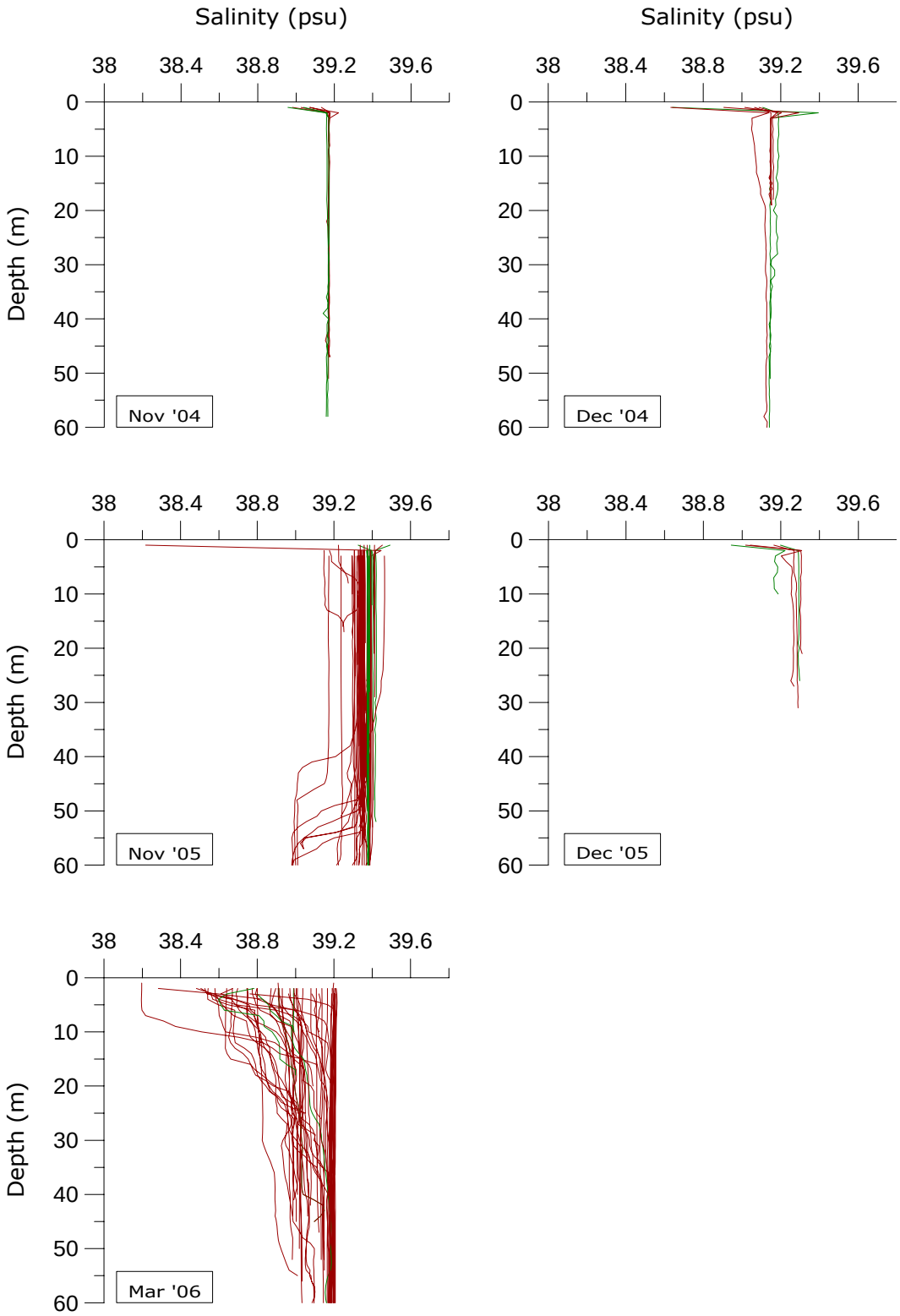


Figure 3.11 The vertical salinity profiles in cold seasons.

Red lines, stations in non-*P. oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

Another difference between the zones was found in depths of light penetration provided by the vertical PAR/Irradiance profiles (Figure 3.12 and 3.12). As it was observed in all the other vertical water profiles the range of the irradiance was narrower in autumn and winter seasons, reaching maximally to 600 μE/m^{2}s. In summer months the irradiance increased, parallel to temperature, up to 1600 μE/m^{2}s.

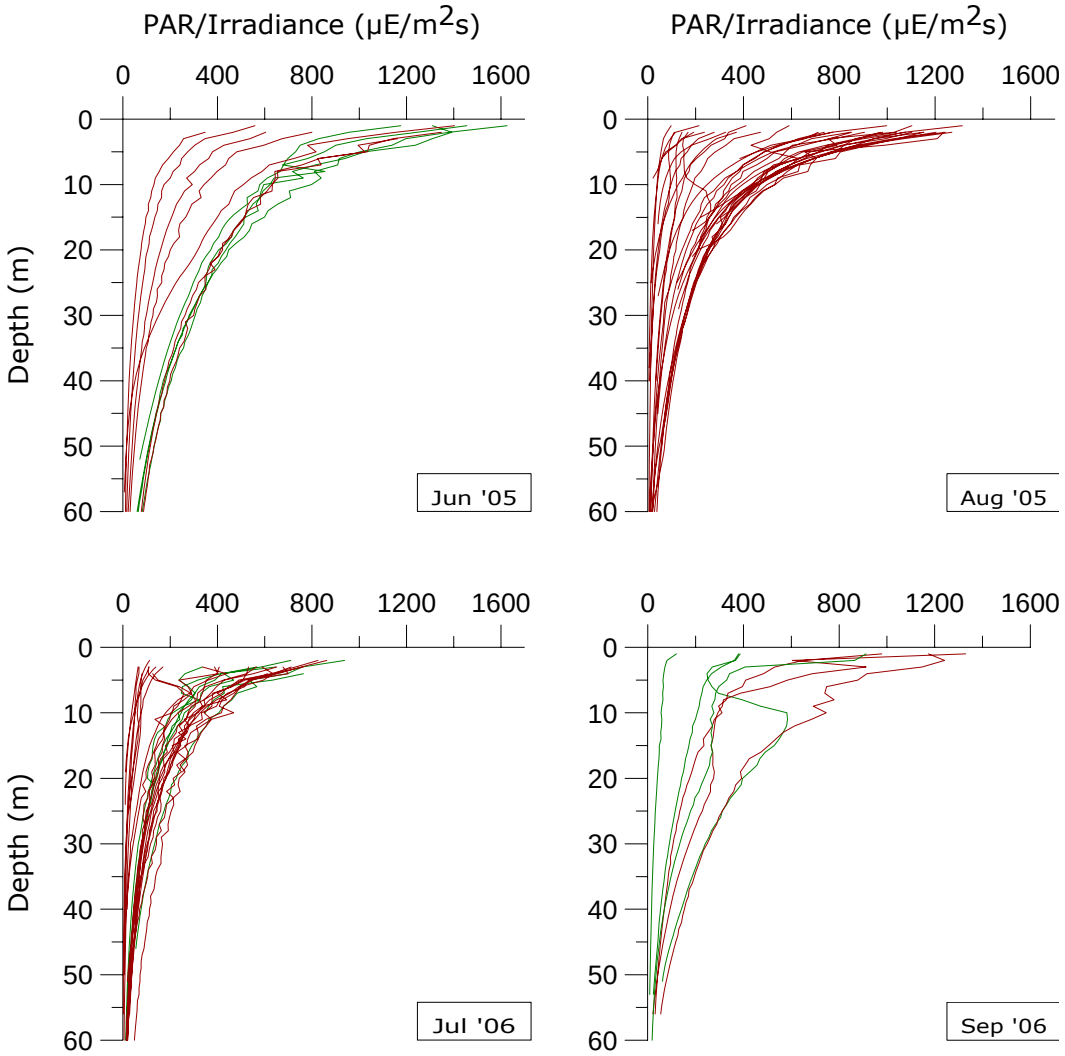


Figure 3.12 The vertical PAR/Irradiance profiles in summer season.

Red lines, stations in non-*P. oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

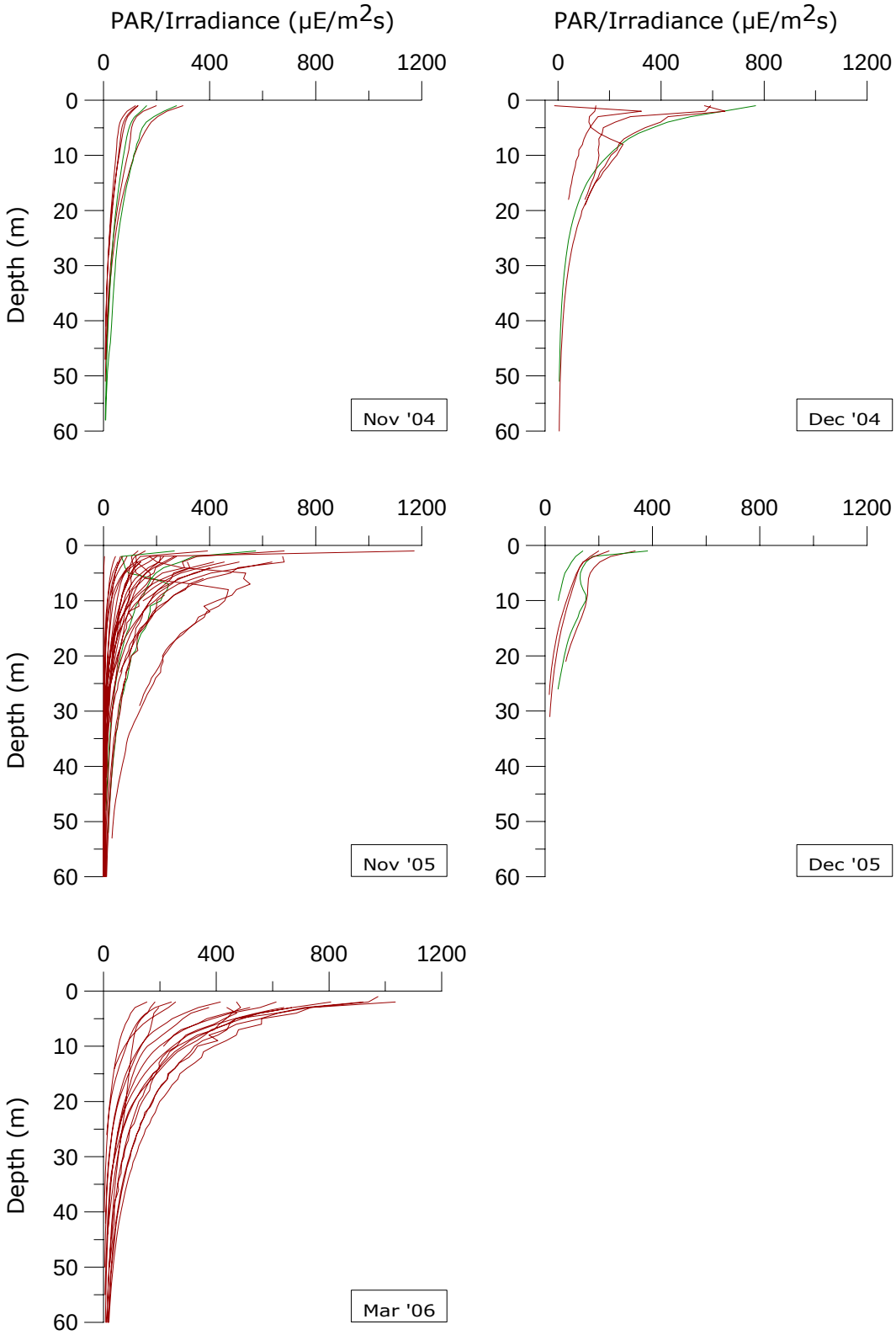


Figure 3.13 The vertical PAR/Irradiance profiles in autumn and winter seasons.

Red lines, stations in non-*P. oceanica* zone; green lines, stations in *P. oceanica* zone; see Figure 2.2 for the position of stations.

Based on PAR profiles, associated coefficients were used to evaluate impacts of optical properties of the water column on the distribution of *Posidonia oceanica*. The light attenuation in an area was then converted into minimum light requirement and deepest depth reached by the plant using equation 2 in section 2.2.2. These values were plotted on the map (from Figure 3.14 to 3.17). In the stations located near to the boundary meadow and on the western side of the boundary, the 10% of the surface irradiance reached deeper than 10 meter during all the seasons. In December 2004, at the station located in region 5 next to the station T3, the theoretical depth limit was found similar to the limits in *P. oceanica* zone. The 50 meter depth contour there, in region 5, is very near to the coast as it is in the region 1 and 2.

Contrarily the light attenuation showed seasonal differences along the eastern coasts. In cold seasons the theoretical seagrass depth limit was too low at station shallower than 50 meter depth in both Mersin and İskenderun Bays (Figure 3.16 and 3.16), whereas in Mersin bay the light penetration increased when going deeper than 50 meter. The north eastern Mediterranean showed theoretical limits deeper than 10 meter depth only in warm seasons, namely in August 2005 and in July 2006 (Figure 3.15 and 3.17). But these stations being located along the 50 meter depth contour were deeper than the natural depth range of *Posidonia oceanica* meadows. The profiles located near to the transplanted frames in station T2 had also no adequate light in both cold and warm seasons of 2005 (Figure 3.15 and 3.15).

A further relation of the theoretical depth with the depth of station was based on the calculation of their ratio. According to the formulation when the ratio of theoretical depth/station depth is equal to one this means that the 10% of the surface irradiance reaches the bottom (Figure 3.19). Thus the seagrass can grow and survive only when the ratio is equal or bigger than 1. However in the present study this ratio was lower than one in both *P. oceanica* zone and non-*P. oceanica* zone.

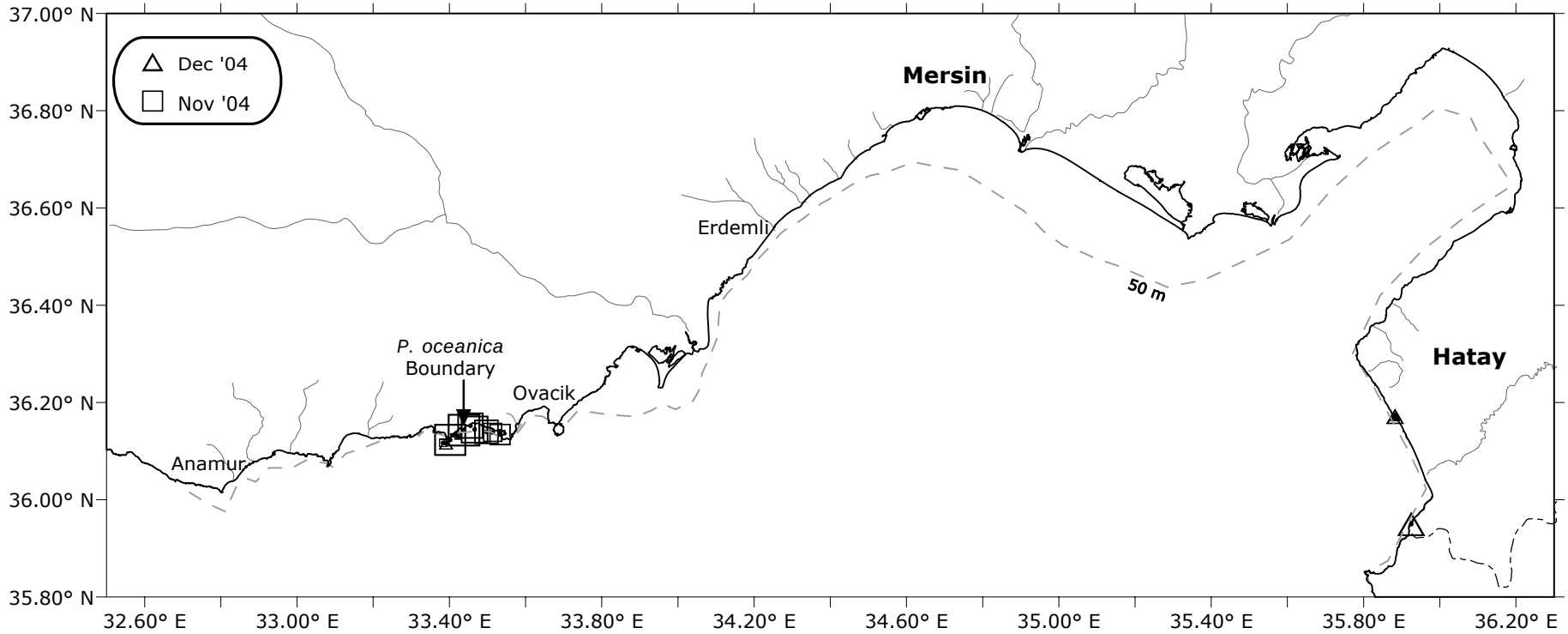


Figure 3.14 Theoretical depth limit of *P. oceanica* growth in the basin according to light penetration in December and November 2004.

"•" shows the stations; "Δ" and "□" indicates the feasible areas where %10 of the surface irradiance reaches more than 10 meter depth, and the signs were scaled according to increasing depth.

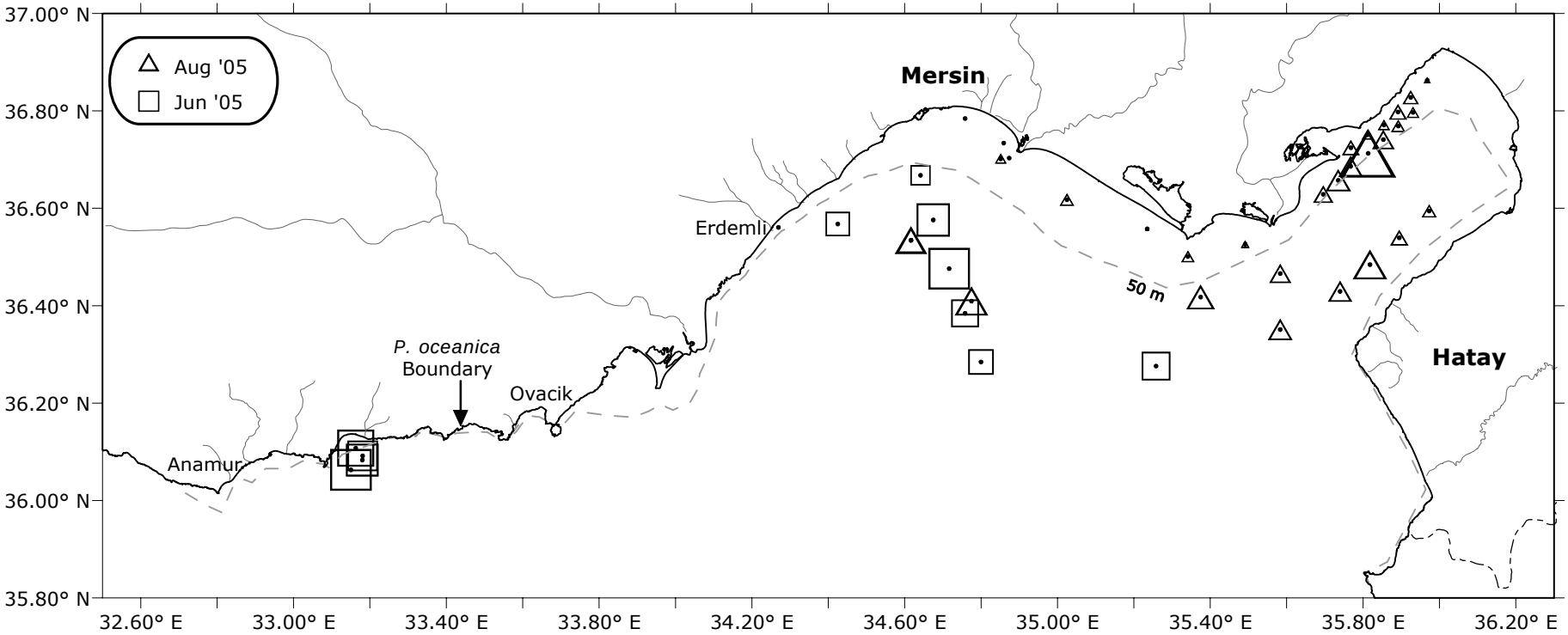


Figure 3.15 Theoretical depth limit of *P. oceanica* growth in the basin according to light penetration in August and June 2005.

"•" shows the stations; "Δ" and "□" indicates the feasible areas where %10 of the surface irradiance reaches more than 10 meter depth, and the signs were scaled according to increasing depth.

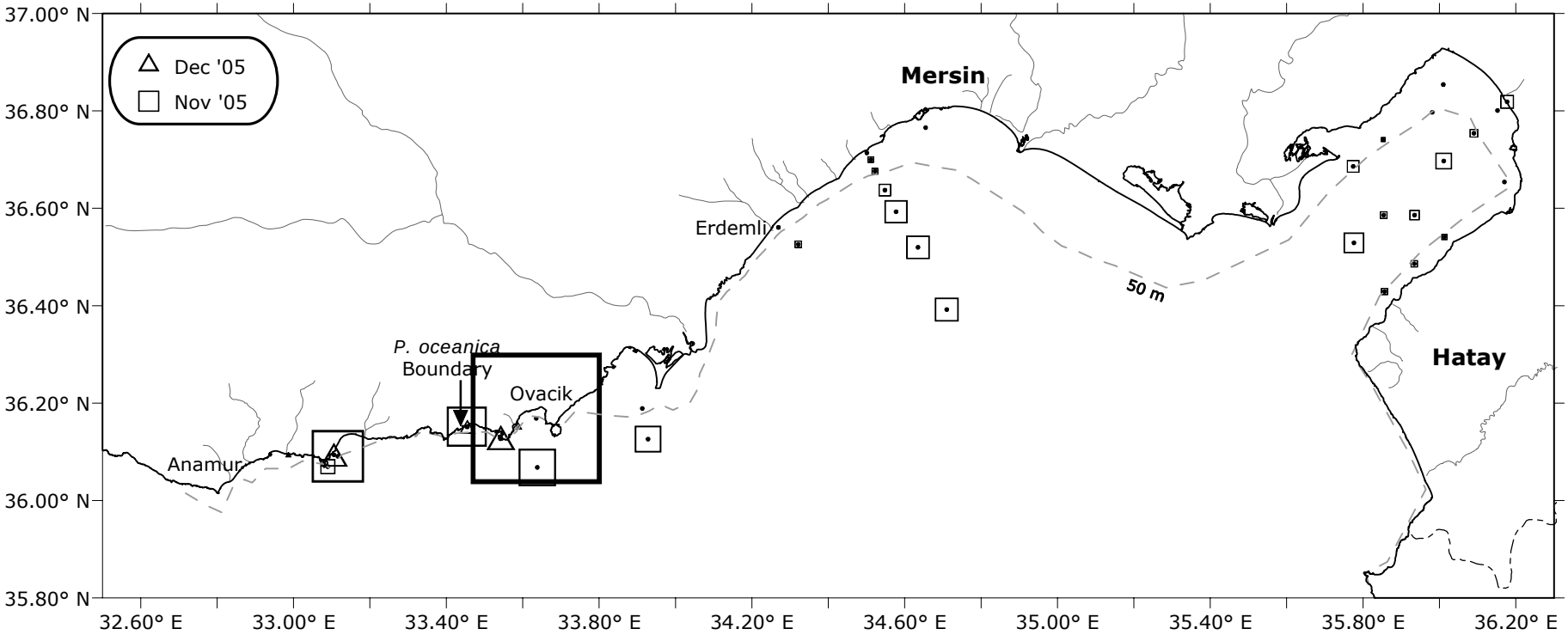


Figure 3.16 Theoretical depth limit of *P. oceanica* growth in the basin according to light penetration in December and November 2005.

"•" shows the stations; "Δ" and "□" indicates the feasible areas where %10 of the surface irradiance reaches more than 10 meter depth, and the signs were scaled according to increasing depth.

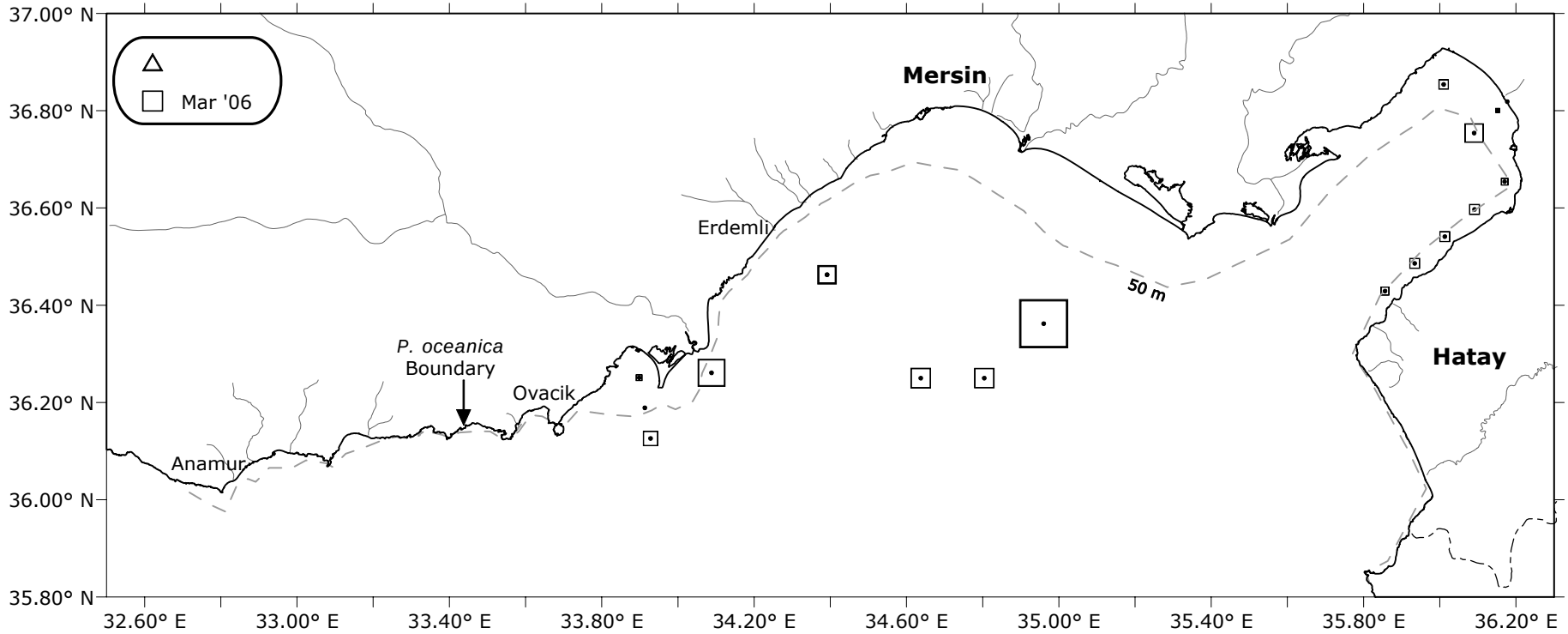


Figure 3.17 Theoretical depth limit of *P. oceanica* growth in the basin according to light penetration in March 2006.

"•" shows the stations; "Δ" and "□" indicates the feasible areas where %10 of the surface irradiance reaches more than 10 meter depth, and the signs were scaled according to increasing depth.

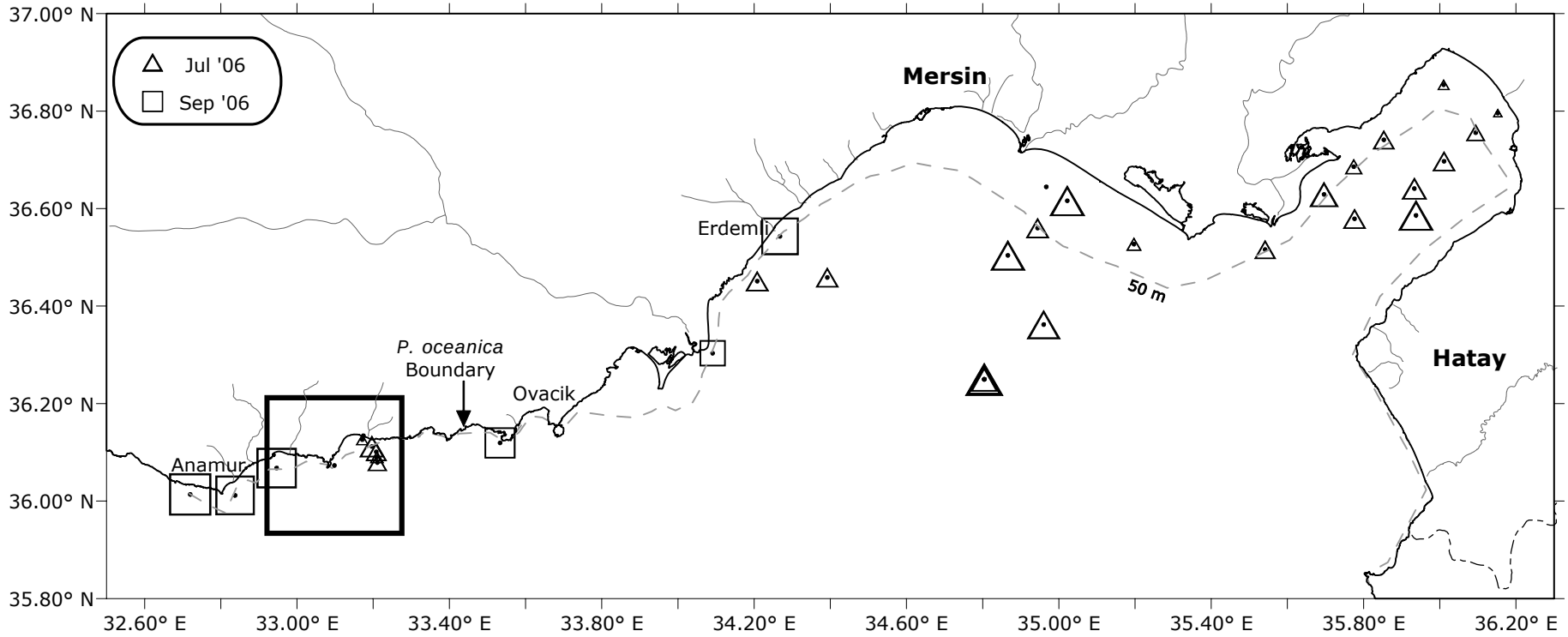


Figure 3.18 Theoretical depth limit of *P. oceanica* growth in the basin according to light penetration in July and September 2006.

"•" shows the stations; "Δ" and "□" indicates the feasible areas where %10 of the surface irradiance reaches more than 10 meter depth, and the signs were scaled according to increasing depth.

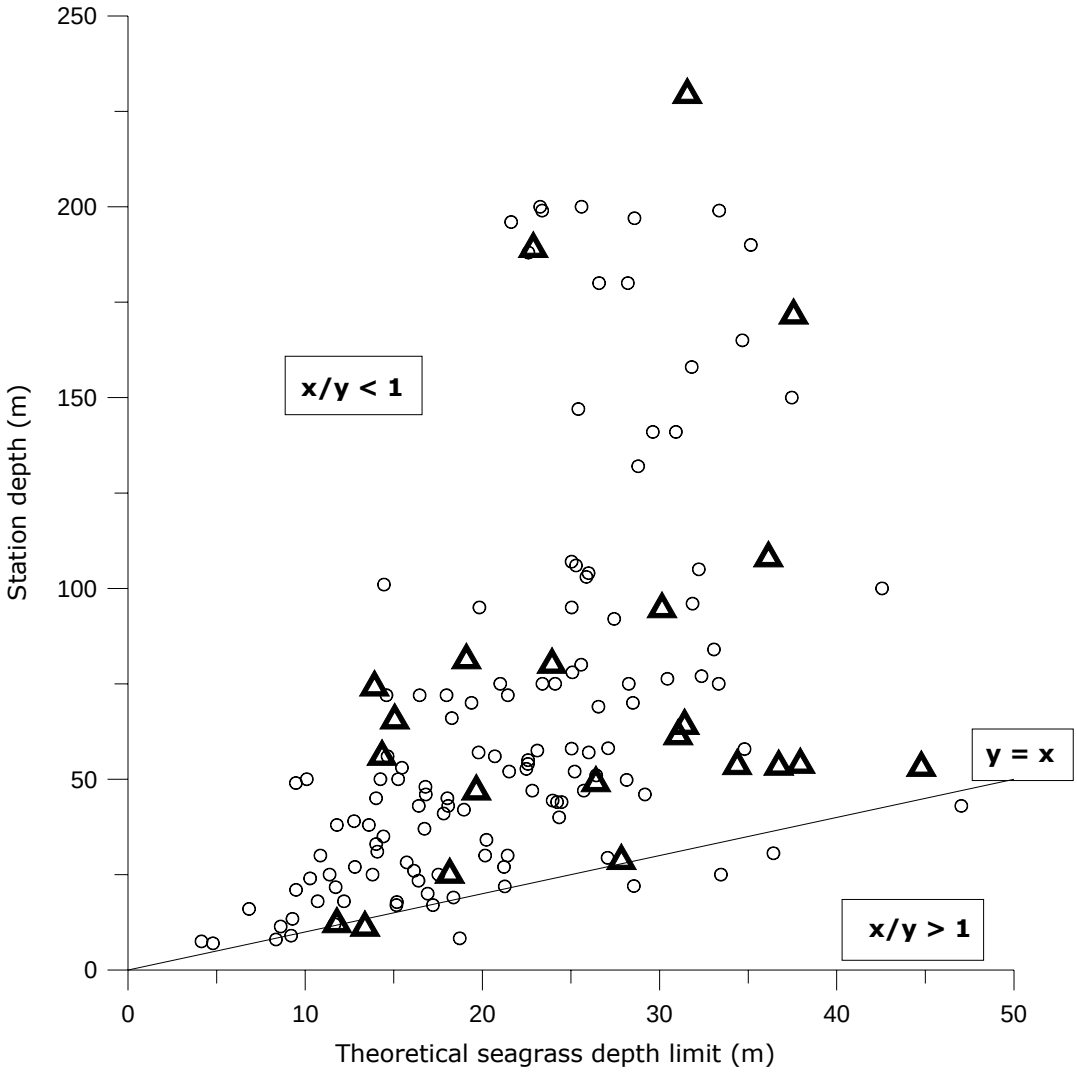


Figure 3.19 Ratio of theoretical seagrass depth limit (x) to the actual depth of the station (y).

"o" non-*P. oceanica* zone, "Δ" *P. oceanica* zone; the function of the solid line is y=x, where the ratio x/y is equal to 1.

3.1.3 Sedimentological and geochemical analysis

The last abiotic descriptor for the study area was related not to water column but to sediment type and its Calcium Carbonate content. The ratio of the size fractions were summarized in Figure 3.20.

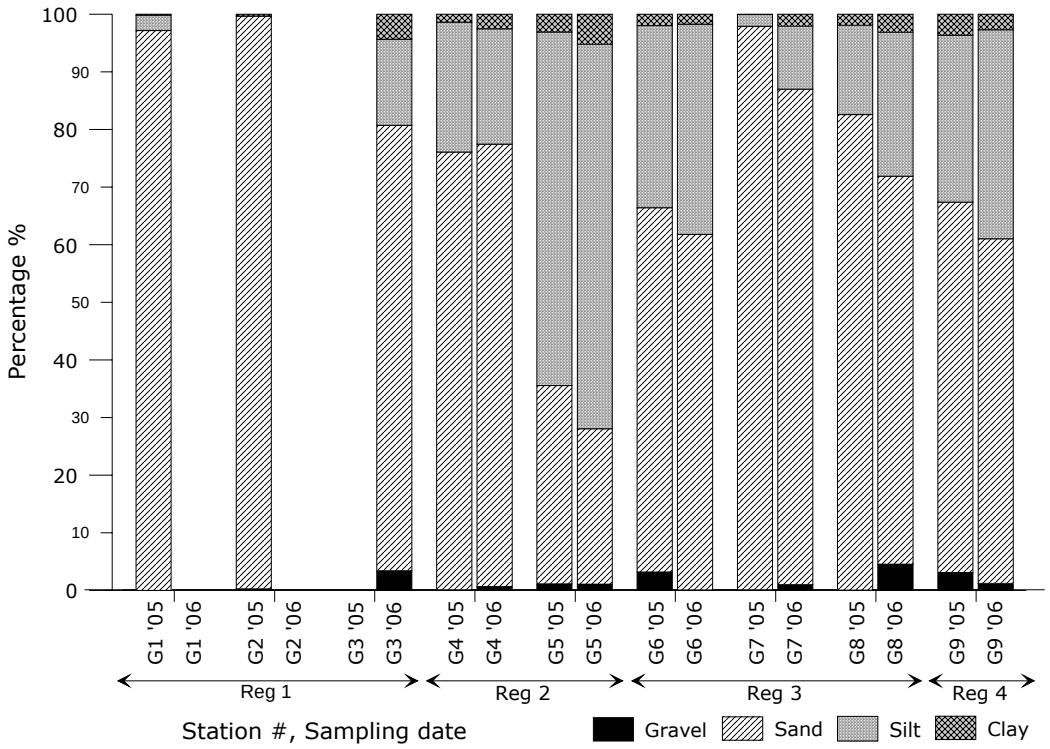


Figure 3.20 Results of grain size analysis classified in 4 size fractions.

Sand was the main constituent of the sediment samples in all stations except G5, where silt dominated and turned the sediment type into muddy character (Table 3.3). This station was at the boundary of *Posidonia oceanica* meadows in north eastern Mediterranean.

The regions differed in the $CaCO_3$ percentages (Figure 3.21). The first six stations, except G2 had higher $CaCO_3$ percentages. On the other hand the stations in regions 3 and 4, where *Posidonia oceanica* meadows are not present, had $CaCO_3$ percentages lower than 40%. Only the station G6 in region 3 showed a high value of $CaCO_3$. For this station, there were recent records of the presence of *Posidonia oceanica* meadows in 1970s (Cirik, 1986), but no remaining were found during this study.

Table 3.2 Classification of sediment types.

YEAR	2005			2006		
STATION #	GRAVEL %	SAND/ MUD	TYPE OF SEDIMENT	GRAVEL %	SAND/ MUD	TYPE OF SEDIMENT
G1	0.0	34.3	Sand	-	-	-
G2	0.3	339.6	Slightly gravelly sand	-	-	-
G3	-	-	-	3.4	4.0	Slightly gravelly muddy sand
G4	0.1	3.2	Slightly gravelly muddy sand	0.7	3.4	Slightly gravelly muddy sand
G5	1.1	0.5	Slightly gravelly sandy mud	1.1	0.4	Slightly gravelly sandy mud
G6	3.2	1.9	Slightly gravelly muddy sand	0.1	1.6	Slightly gravelly muddy sand
G7	0.1	47.0	Slightly gravelly sand	1.0	6.6	Slightly gravelly muddy sand
G8	0.0	4.7	Slightly gravelly muddy sand	4.5	2.4	Slightly gravelly muddy sand
G9	3.1	2.0	Slightly gravelly muddy sand	1.2	1.5	Slightly gravelly muddy sand

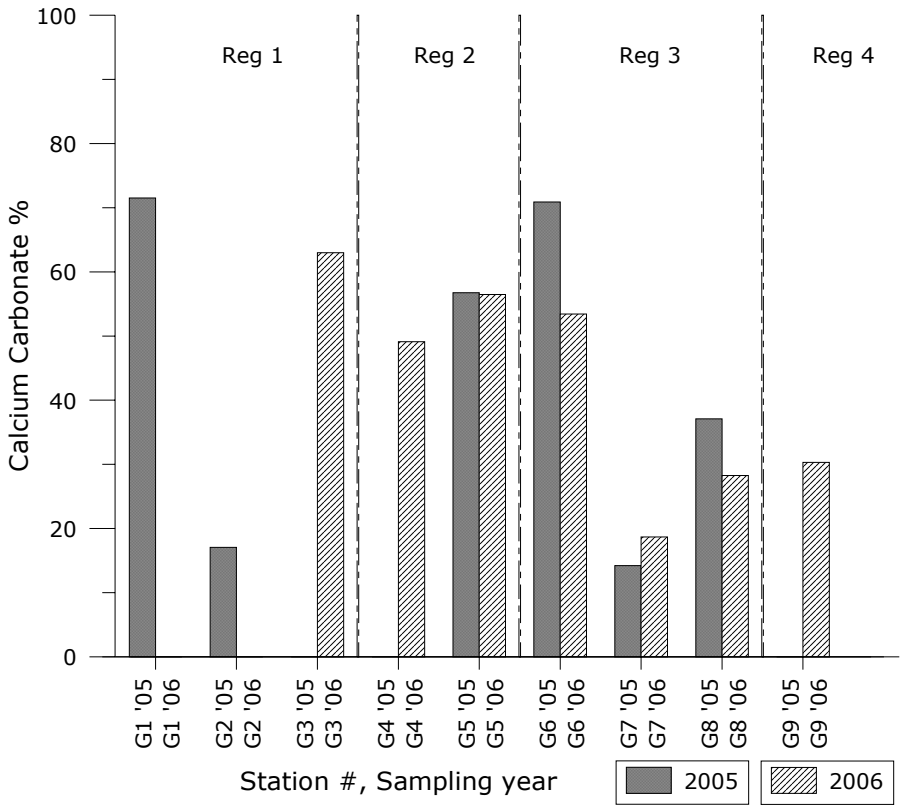


Figure 3.21 Results of $CaCO_3$ analysis in 4 regions.

3.2 Structural descriptors

In September 2004, along the surveyed area no evidence of *Posidonia oceanica* meadows was found in infralittoral zone eastward from Turgutlar Bay. Also there were not any detached and transported living/death shoots encountered on beaches. Therefore the meadow at Turgutlar Bay (N 36° 09.197′, E 33° 26.801′) was accepted as boundary meadow in north eastern Levant Sea during this study.

The reference cement blocks used to mark the boundary of *Posidonia oceanica* distribution in Turgutlar Bay were still at the same edges of the *Posidonia oceanica* patches after 2 years of their placement. During the study period, the topographic limit of the boundary meadow did not showed any changes.

The monitoring of the *Posidonia oceanica* meadows found on the western of this boundary gave a general view about the state of meadows in north eastern Mediterranean Sea. All measured structural parameters were summarized in Table 3.3. The highest mean meadow density and the maximum lower depth limit were observed in station M3 (Figure 2.1). This station was located in an urbanized area. The second healthiest meadow having high shoot density (HSD), 0% fragmentation rate and deeper lower depth limit, was found in station M4, which was located around a remote island near the same remote area. The station M2 (Figure 2.1) located in a bay with touristic settlement had higher fragmentation rates though having high meadow densities. The minimum meadow density was recorded at station M6 (Figure 2.1), which is the meadow at the boundary in Turgutlar Bay, having the minimum lower depth limit among all the other stations. The second station having 0% fragmentation rate was the station M1 (Figure 2.1), located near a harbor. It had the normal density at all depths.

Regardless the differences in meadows densities, in all stations the shoot density decreased with increasing depth (Table 3.4). Except the station M2 (Figure 2.1), in all other stations the correlation was significant. But not all the stations had the same decreasing rate (Figure 3.22). The trends of stations M3 and M4 (Figure 2.1) were related to depth with a higher coefficient (R^2= 0.93 in M3 and R^2=0.90 in M4). These were the same stations found to be the healthiest due to having high meadow density and extending up to 30 meter depths. In stations

M1 and M6 (Figure 2.1), the significance of dependency on depth was much lesser as compared to M3 and M4.

Table 3.3 Results of structural descriptors of the *Posidonia oceanica* meadows in the study area.

Disturbed beds: LSD [lower sub-normal density], Beds in equilibrium: ND [normal density] and HSD [higher sub-normal density].

STAT #	LOWER DEPTH LIMIT (m)	DEPTH (m)	FRAGMEN-TATION (%)	# OF REPLICA	MEAN LENGTH OF LONGEST LEAVES (cm)	MEAN SHOOT DENSITY (#/m^2)	TYYPE OF MEADOW
M1	24.2	20	0	3	58.3	336	ND
		15	0	3	62.6	352	ND
		10	0	3	69.9	528	ND
M2	23.6	20	21.8	3	59.1	412	HSD
		15	27.9	3	44.3	539	HSD
M3	31.8	25	19.7	3	23.3	224	ND
		20	28.8	3	24.0	304	ND
		15	10.2	3	24.0	592	HSD
		10	10.8	3	33.9	843	HSD
M4	30.3	30	0	1	56.7	192	ND
		25	0	2	53.5	240	ND
		20	0	1	80.0	528	HSD
M5	28	25	28.4	3	12.5	176	ND
		20	0.64	3	21.3	347	ND
		15	22.8	3	25.1	496	HSD
		10	0.85	3	22.0	475	ND
M6	19.7	15	not measured	3	40.7	208	LSD
		10	not measured	3	36.1	469	ND
		5	not measured	2	30.4	528	ND

Table 3.4 Correlation of shoot density and depth.

* significant at $p<0.05$.

STAT #	r	p	n
M1	-0.76	0.011 *	10
M2	-0.73	0.060	7
M3	-0.95	0.000 *	13
M4	-0.95	0.004 *	6
M5	-0.87	0.000 *	13
M6	-0.93	0.000 *	9

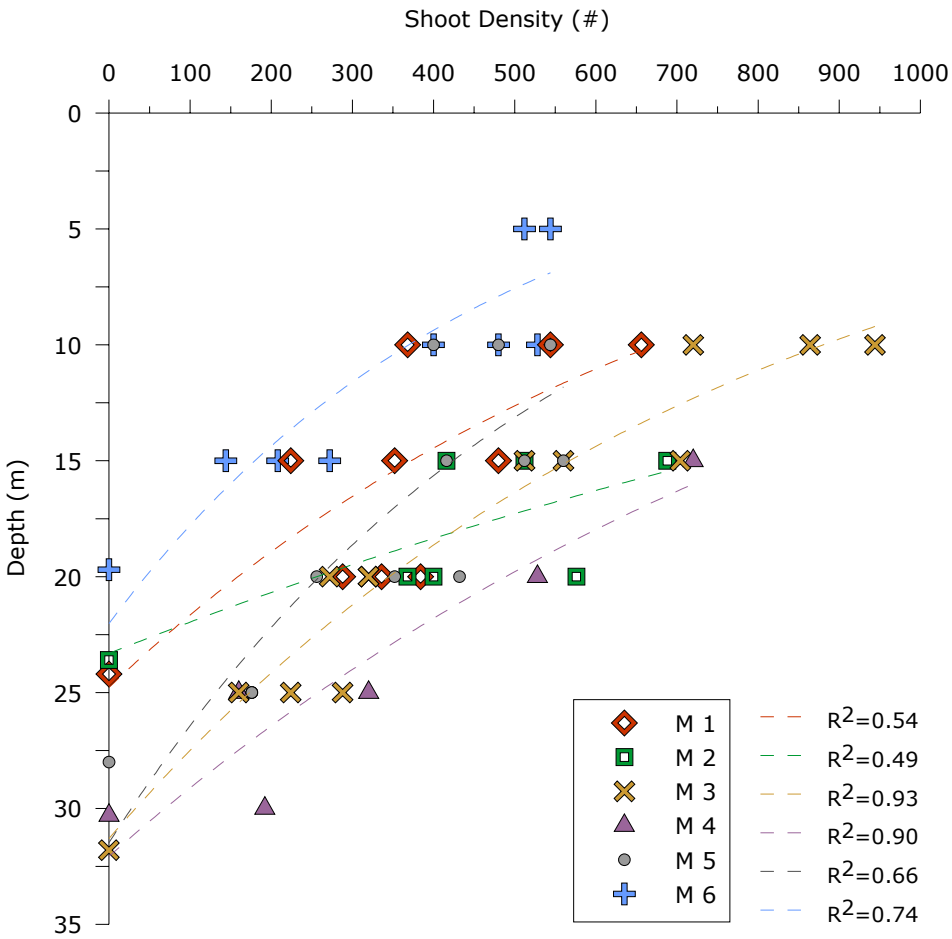


Figure 3.22 The dependency of shoot density to depth.

R^2 gives the coefficient of determination.

The length of the longest leaves in a shoot was considered as canopy heights. These measurements were largely dependent on sampling months. In general, the canopy height became shortest after the removal of longest adult leaves due to the storms. In the present study the sampling was carried out in different seasons, thereof the differences among all stations could not be compared (Figure 3.23). The stations sampled in December had shorter leaves than those sampled in spring because *Posidonia oceanica* sheds its leaves in fall.

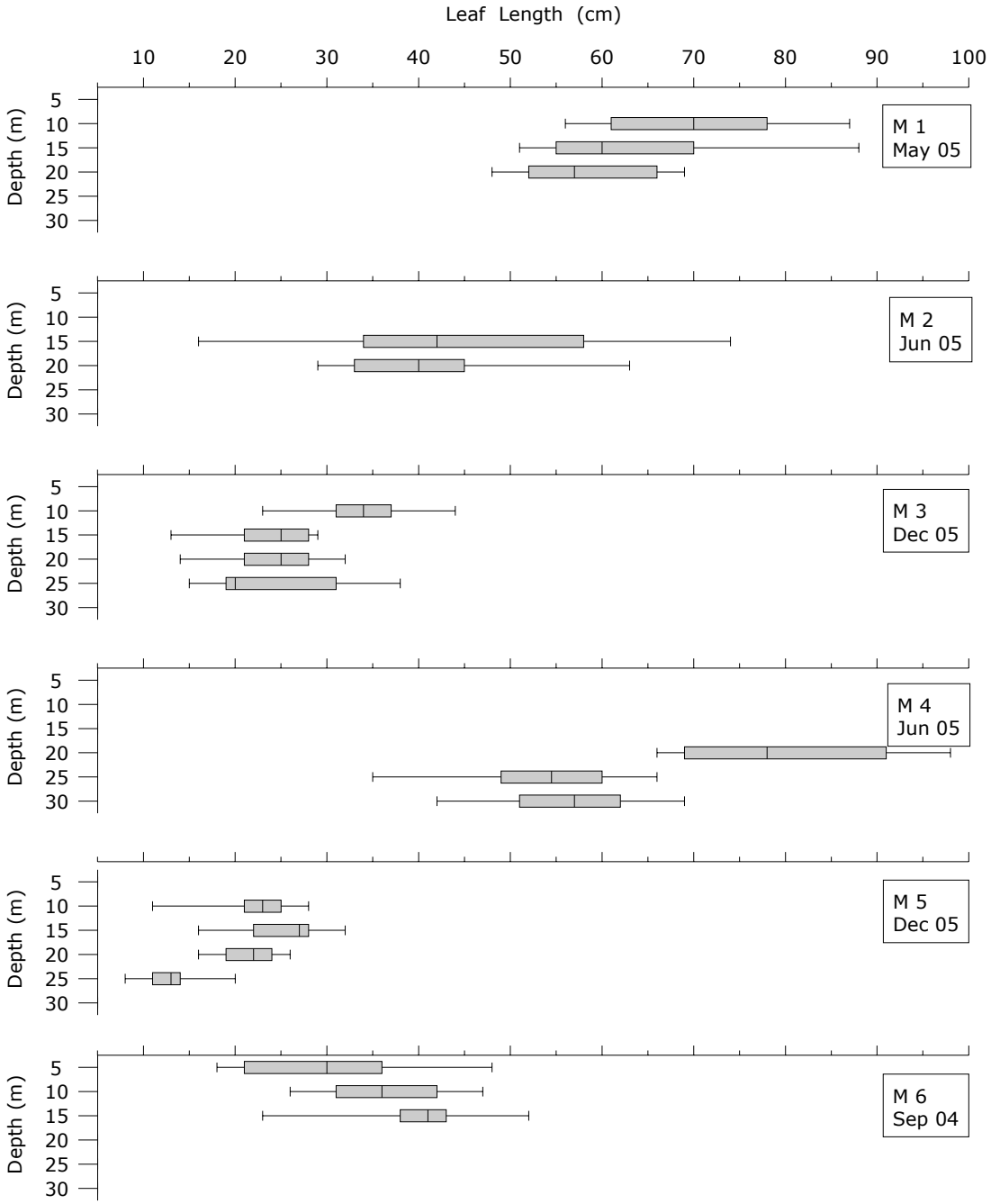


Figure 3.23 Leaf length ranges of *Posidonia oceanica* with respect to depth.

Still it was possible to compare the paired stations such as M1, M2 and M3 (Figure 3.23) in warm season of 2005, M3 and M5 (Figure 3.23) both in December 2005, which showed variations among themselves. Going from western to eastern stations, e.g. from M1 to M2 and from M3 to M5 (Figure

3.23), the leaf length decreased. An exception in this likelihood was observed only in station M4 (Figure 3.23), which had higher leaf length than M2 though being located east to that station. This could be related to being located around a remote island that had a steep slope on one side.

In spite of the longitudinal differences in leaf length, all stations, except the station M5 (Figure 3.23), had the same relationship between leaf length and depth. As it is also a general property of seagrasses, the leaf length decreased with increasing depth.

3.3 Functional descriptors

The parameters under the section of functional descriptors provided both present and past growth rates of *Posidonia oceanica* and its responses to environmental changes, with differences among all the stations and their depths.

The leaf formation rate in stations L2 and L3 (Figure 2.1) increased with increasing depth (Figure 3.24 A). The station L1 could not be monitored for changes with respect to depth due to lack of sampling and the shoots at station L4 was from the transplants so this was a single patch without any control in region 5 (Figure 2.1). Comparison of fluctuations in years showed that the leaf formation rate was higher in all years in station L3, changed between 8 to 11 leaves per year, than in other stations, e.g. 6-8 leaves in L2 (Figure 3.24 A). Contrarily this station had the lowest rhizome production rates both in length and weight (Figure 3.24 B and C).

Rhizome elongation and rhizome biomass were strongly related parameters, so they showed similar patterns and considered totally as rhizome productions. The rhizome production was highest in transplanted cuttings at L4 (Figure 3.24). The stations L2 and L3 (Figure 3.24), though having the same decline in leaf formation rate with respect to depth, differed in rhizome productions. With respect to depth, it increased when going deeper in station L3 located at the boundary meadow, whereas it decreased in L2 (Figure 3.24).

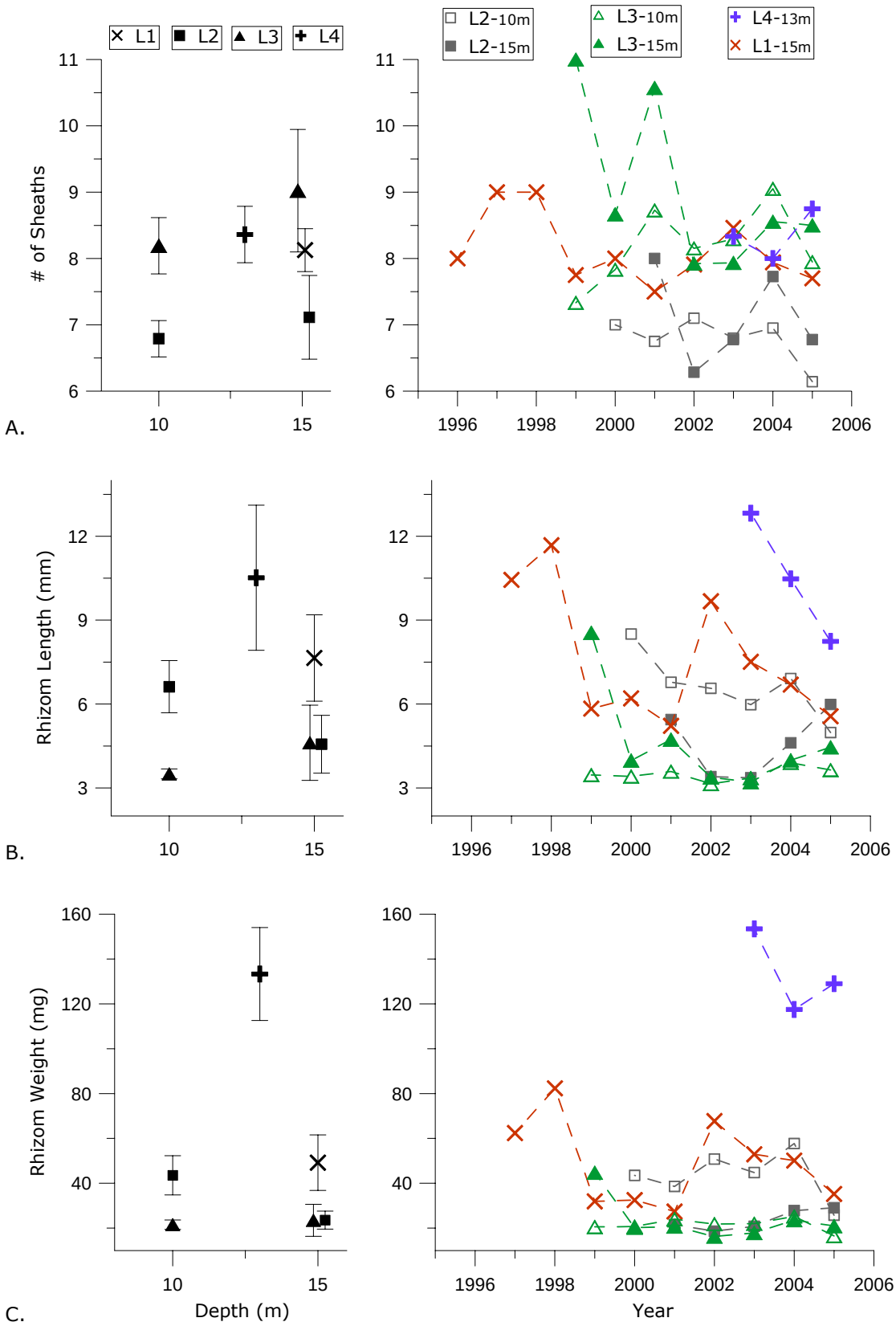


Figure 3.24 Changes of leaf formation rate (# of sheaths) and rhizome production (both in length and weight) with respect to depth and time.

Flowering was recorded in 3 shoots out of 20 only in station L1-15m, corresponding to years 1999 and 2004, which happened just after the sharp increase in maximum temperature in region 1 in 1998 and 2003 (Figure 3.9 A).

Another advantage of the lepidochronology was the determination of cycles by sheath thicknesses which were completed in one year. The cycle started with a minimum in the winter and completed in the winter of the next year; having the maximum thickness just in the middle, in warm season (Figure 3.25). In the present study, as given in the Figure 3.25 by two x- axes, the start of the first lepidochronological year corresponded to winter of 2005.

Though the overlapping periodicity could be visualized from these raw data of each shoot in each station, there were some shifts and anomalies among the shoots. These shifts came out from instability of the number of sheaths produced per year (=leaf formation rate) and their formation time, whereas the anomalies appeared due the flowering and underdeveloped sheaths (called as "bractea"). Additionally not all the shoots were enough long to supply information about previous years. Thus, the most complex feature of the lepidochronological analysis was the fitting of lepidochronological cycles from different number of shoots for each station and their adjustment for variance analysis between stations.

Nonlinear regression models, as explained in chapter 2.4, were used to resolve this problem. The estimates for each shoot were summarized from Table 3.5 to Table 3.10. Best estimates were found for b1 and a1 with p values lower than 0.00 in all stations for each shoot. These were describing the horizontal shift and magnitude of amplitude, respectively. The variations in estimates of a2 and b3 accounted for the differences of growth among stations.

In all stations the vertical shift rate (b3) has a negative value meaning that sheath thicknesses had increased in last years in the same manner as SST did (Table 3.11). The station L2 (Table 3.11) had the highest rate at both depths according to both models. It had also higher amplitude (a1) when compared to L3 (Table 3.11 and Figure 3.26 a.-b. and c.-d.). This result described the bigger differences between maximum and minimum sheath thicknesses observed in L2 (between 200 and 1000µm) while the sheath thickness oscillated between 200 and 800µm in L3.

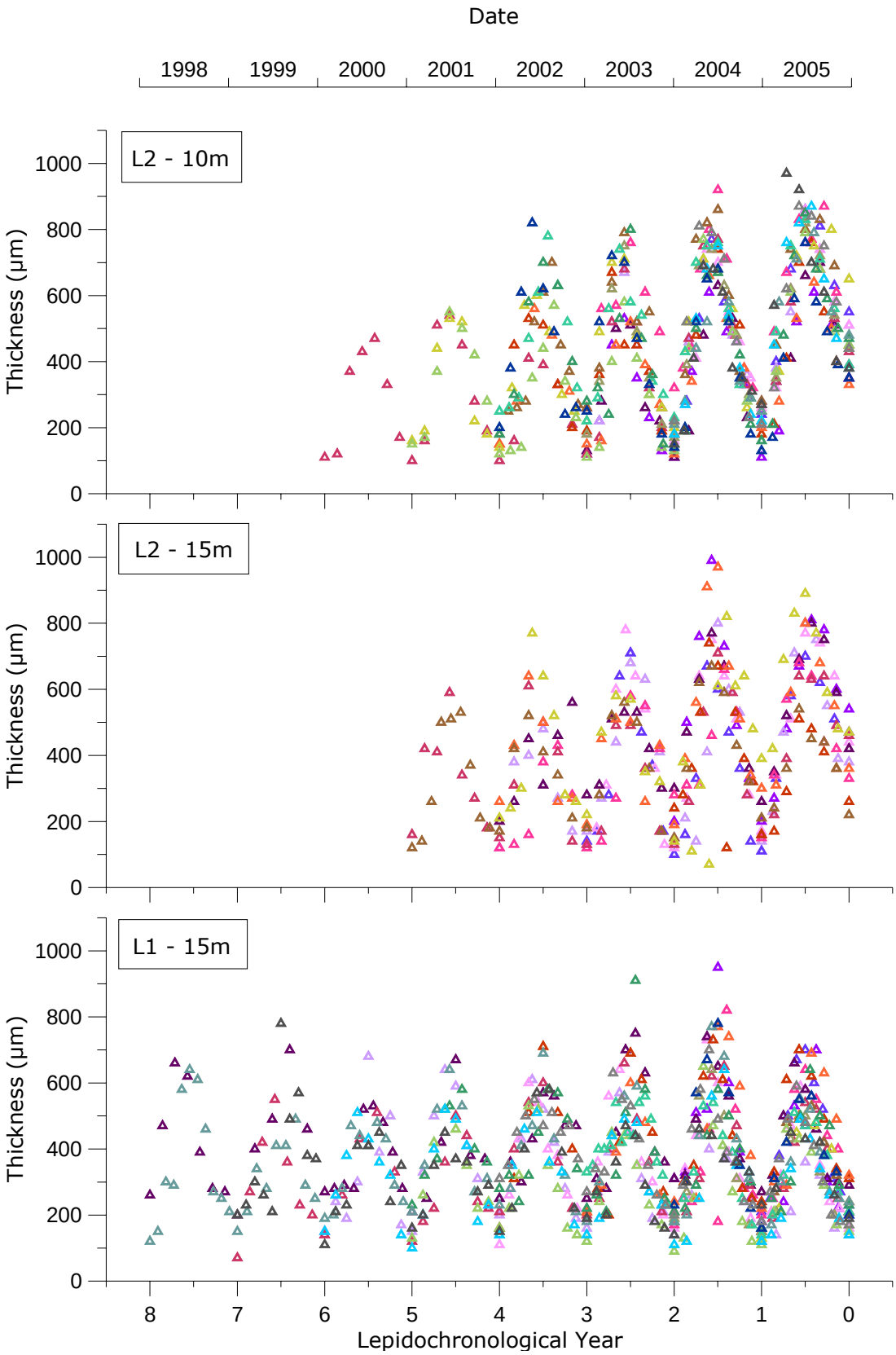


Figure 3.25 Lepidochronological cycles.

Each color in each station represents one shoot.

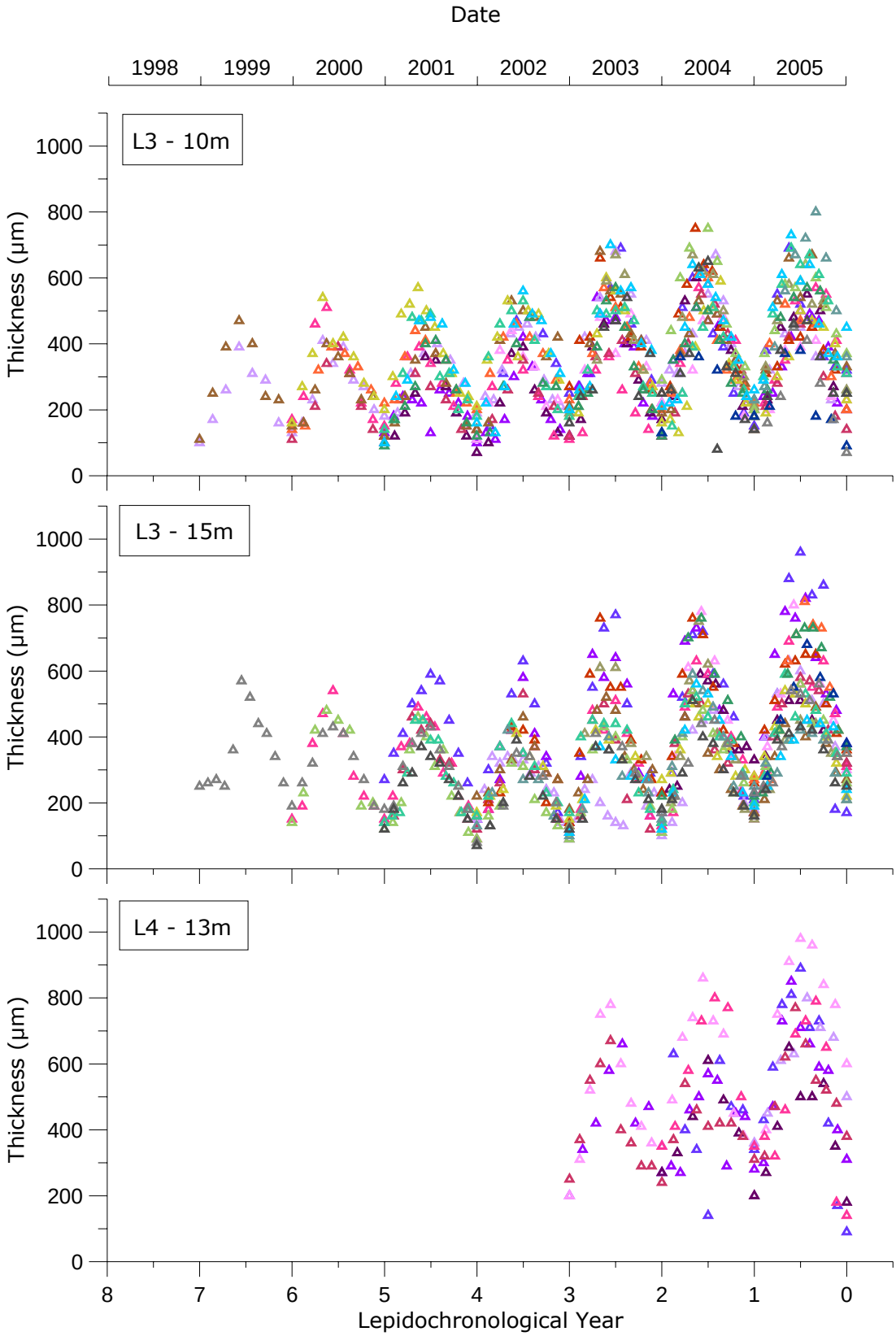


Figure 3.24 continue.

Table 3.5 Estimates of the parameters for each shoot in Station L1 (Figure 2.1) at 15 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L1-15m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	234.70	21.61	0.00	3.48	37.50	0.93	1.67	0.06	0.00	-23.81	17.44	0.21	455.00	0.99
2	235.13	82.03	0.01	2.46	69.38	0.97	1.52	0.20	0.00	10.83	28.42	0.71	440.00	0.83
3	114.37	37.49	0.00	16.01	10.28	0.13	1.75	0.11	0.00	25.88	3.56	0.00	240.00	0.84
4	193.85	28.83	0.00	-5.47	12.53	0.67	5.24	0.08	0.00	-3.05	4.71	0.52	375.00	0.92
5	195.28	31.73	0.00	-8.25	7.10	0.25	1.60	0.10	0.00	-9.52	2.68	0.00	465.00	0.80
6	226.30	81.22	0.01	-43.61	65.61	0.52	1.22	0.23	0.00	-44.12	24.94	0.10	420.00	0.77
7	195.88	27.26	0.00	-3.45	6.83	0.62	1.59	0.08	0.00	-4.73	2.62	0.08	350.00	0.89
8	208.59	37.06	0.00	4.30	16.40	0.80	1.59	0.09	0.00	-19.77	6.22	0.00	470.00	0.91
9	242.97	47.40	0.00	-19.18	27.48	0.49	1.02	0.11	0.00	-20.12	10.43	0.07	455.00	0.91
10	99.28	40.37	0.07	144.33	70.53	0.11	1.52	0.16	0.00	79.04	36.52	0.10	340.00	0.97
11	60.05	52.59	0.37	231.40	102.93	0.15	1.07	0.18	0.00	103.09	49.04	0.17	300.00	0.98
12	153.54	33.64	0.00	-52.24	28.24	0.09	5.06	0.09	0.00	27.26	11.34	0.04	325.00	0.96
13	181.49	23.97	0.00	-1.21	8.25	0.88	5.20	0.07	0.00	5.08	2.97	0.10	285.00	0.93
14	188.77	30.72	0.00	29.55	15.85	0.07	4.70	0.11	0.00	30.65	5.46	0.00	325.00	0.88
15	223.61	32.09	0.00	-13.73	11.17	0.23	1.09	0.09	0.00	-1.77	4.14	0.67	400.00	0.88
16	184.61	21.79	0.00	1.49	3.13	0.64	1.58	0.06	0.00	2.77	1.10	0.01	355.00	0.88
17	179.07	26.15	0.00	0.24	7.48	0.97	4.86	0.08	0.00	3.62	2.85	0.21	305.00	0.89
18	135.69	29.47	0.00	-89.11	24.69	0.00	4.89	0.07	0.00	64.85	10.02	0.00	360.00	0.97
19	224.59	24.94	0.00	30.86	10.93	0.01	5.23	0.08	0.00	9.53	4.02	0.02	385.00	0.91
20	119.94	34.53	0.00	4.94	8.07	0.54	1.46	0.12	0.00	-1.09	2.82	0.70	340.00	0.75
Mean	179.89			11.64			2.69			11.73			369.50	
SE	11.37			15.14			0.39			8.01			14.68	

Table 3.6 Estimates of the parameters for each shoot in Station L2 (Figure 2.1) at 10 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L2-10m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	145.46	82.87	0.11	73.65	68.45	0.31	1.60	0.22	0.00	-48.28	28.22	0.12	550.00	0.87
2	124.96	68.92	0.09	-36.89	37.11	0.34	4.91	0.20	0.00	-17.47	14.19	0.24	360.00	0.82
3	130.45	55.77	0.03	44.96	31.04	0.17	1.80	0.15	0.00	-42.65	12.06	0.00	520.00	0.88
4	159.89	60.12	0.02	65.88	48.57	0.20	1.52	0.15	0.00	-59.45	19.34	0.01	560.00	0.93
5	185.00	55.87	0.00	-5.55	31.55	0.86	4.68	0.16	0.00	-52.30	12.60	0.00	455.00	0.88
6	234.41	61.38	0.00	2.35	36.14	0.95	1.60	0.14	0.00	5.20	13.87	0.71	540.00	0.86
7	242.23	36.42	0.00	7.89	10.23	0.45	4.92	0.09	0.00	-57.60	3.73	0.00	560.00	0.92
8	222.71	54.52	0.00	11.18	23.16	0.63	4.92	0.15	0.00	-29.28	9.08	0.00	470.00	0.84
9	176.14	37.56	0.00	10.19	15.87	0.53	1.49	0.10	0.00	-23.02	6.11	0.00	420.00	0.93
10	242.30	59.79	0.00	5.90	24.14	0.81	4.83	0.13	0.00	-37.17	8.62	0.00	555.00	0.85
11	115.37	58.58	0.06	32.42	19.58	0.11	2.06	0.14	0.00	-39.70	6.82	0.00	525.00	0.84
12	169.80	50.01	0.00	-46.26	28.19	0.12	5.06	0.11	0.00	-39.98	10.68	0.00	535.00	0.92
13	223.85	47.88	0.00	-7.04	15.92	0.66	1.60	0.12	0.00	-49.19	5.75	0.00	505.00	0.87
14	238.32	49.76	0.00	-4.54	20.44	0.83	1.73	0.11	0.00	-20.48	7.27	0.01	525.00	0.88
15	233.24	48.72	0.00	5.76	21.66	0.79	1.55	0.11	0.00	-27.48	8.43	0.00	505.00	0.88
16	147.51	69.22	0.06	-42.71	54.93	0.45	4.84	0.20	0.00	-51.92	21.16	0.03	520.00	0.89
17	235.21	56.20	0.00	-34.03	47.24	0.49	4.95	0.12	0.00	-46.83	18.89	0.03	545.00	0.94
18	189.55	45.10	0.00	-29.40	19.66	0.15	5.16	0.10	0.00	-1.99	7.47	0.79	445.00	0.89
19	168.73	83.37	0.07	-101.65	71.51	0.18	4.98	0.18	0.00	5.67	29.77	0.85	540.00	0.87
20	286.44	65.20	0.00	9.19	55.07	0.87	5.25	0.13	0.00	-118.37	20.44	0.00	620.00	0.92
Mean	193.58			-1.93			3.47			-37.61			512.75	
SE	10.77			9.03			0.37			6.12			13.02	

Table 3.7 Estimates of the parameters for each shoot in Station L2 (Figure 2.1) at 15 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L2-15m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	140.30	58.31	0.03	63.70	31.98	0.06	1.61	0.13	0.00	-14.25	11.92	0.25	405.00	0.89
2	39.01	91.19	0.68	205.37	77.93	0.02	1.77	0.21	0.00	42.86	33.18	0.22	505.00	0.85
3	305.58	50.73	0.00	-39.77	22.65	0.09	1.32	0.12	0.00	-37.50	9.02	0.00	470.00	0.88
4	154.65	57.57	0.01	69.16	30.78	0.04	1.59	0.11	0.00	-16.53	11.39	0.16	470.00	0.91
5	228.71	50.83	0.00	-38.51	22.07	0.09	1.41	0.17	0.00	-39.70	8.52	0.00	530.00	0.82
6	178.49	48.48	0.00	-0.23	21.10	0.99	1.15	0.15	0.00	-32.91	8.18	0.00	415.00	0.86
7	182.23	51.49	0.00	-4.27	17.54	0.81	4.86	0.15	0.00	-14.98	6.75	0.03	400.00	0.81
8	76.87	88.67	0.40	66.56	71.60	0.37	1.65	0.32	0.00	46.79	27.65	0.11	335.00	0.68
9	263.71	66.43	0.00	-28.57	29.08	0.34	1.81	0.17	0.00	-41.89	11.09	0.00	550.00	0.81
10	156.11	32.19	0.00	-12.16	10.78	0.27	4.99	0.09	0.00	-7.84	4.02	0.06	375.00	0.89
11	171.71	76.88	0.03	-1.62	33.46	0.96	4.61	0.24	0.00	-81.49	12.98	0.00	640.00	0.69
Mean	172.49			25.42			2.43			-17.95			463.18	
SE	22.94			21.82			0.46			11.16			26.80	

Table 3.8 Estimates of the parameters for each shoot in Station L3 (Figure 2.1) at 10 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L3-10m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	174.47	38.31	0.00	-0.94	16.91	0.96	4.92	0.12	0.00	-17.02	6.36	0.01	420.00	0.85
2	177.79	28.01	0.00	-24.08	9.47	0.01	1.57	0.12	0.00	-32.40	3.49	0.00	365.00	0.84
3	171.75	30.25	0.00	-8.23	7.55	0.28	1.59	0.11	0.00	-4.51	2.72	0.10	325.00	0.79
4	132.95	35.63	0.00	2.38	14.95	0.87	4.64	0.15	0.00	15.26	5.56	0.01	275.00	0.80
5	196.74	29.44	0.00	12.02	9.86	0.23	4.86	0.09	0.00	-24.80	3.57	0.00	345.00	0.90
6	121.04	39.94	0.00	2.47	11.27	0.83	1.86	0.17	0.00	-34.28	4.27	0.00	425.00	0.72
7	169.96	20.13	0.00	12.88	5.76	0.03	4.74	0.08	0.00	-19.40	2.22	0.00	330.00	0.91
8	104.74	39.03	0.01	-38.85	22.50	0.10	5.07	0.12	0.00	56.80	8.24	0.00	315.00	0.87
9	170.89	19.63	0.00	10.63	5.69	0.07	4.98	0.07	0.00	-10.46	2.05	0.00	370.00	0.91
10	175.50	24.91	0.00	-5.62	6.33	0.38	1.70	0.08	0.00	-24.06	2.34	0.00	425.00	0.88
11	167.02	29.50	0.00	-6.99	8.42	0.41	1.53	0.10	0.00	10.51	3.02	0.00	320.00	0.80
12	148.77	34.22	0.00	33.36	18.86	0.09	1.60	0.09	0.00	5.43	7.04	0.45	400.00	0.92
13	79.42	43.08	0.08	-91.25	36.63	0.02	4.95	0.14	0.00	66.61	14.64	0.00	420.00	0.89
14	182.80	28.38	0.00	5.72	9.82	0.56	4.88	0.09	0.00	-34.08	3.70	0.00	460.00	0.88
15	173.22	24.61	0.00	5.25	8.30	0.53	4.73	0.08	0.00	-22.94	3.00	0.00	375.00	0.92
16	181.53	55.40	0.02	146.53	102.70	0.20	0.97	0.11	0.00	50.97	44.47	0.30	515.00	0.97
17	177.34	26.06	0.00	0.38	9.31	0.97	1.55	0.08	0.00	-38.33	3.53	0.00	495.00	0.90
18	150.02	39.27	0.01	18.11	34.71	0.62	5.30	0.18	0.00	-13.19	14.36	0.39	280.00	0.89
19	223.64	32.72	0.00	-120.46	56.60	0.10	1.61	0.13	0.00	-67.52	26.78	0.07	295.00	0.98
20	118.30	58.36	0.05	-13.86	33.09	0.68	4.84	0.22	0.00	16.24	12.27	0.20	305.00	0.71
Mean	159.90			-3.03			3.40			-6.06			373.00	
SE	7.57			11.30			0.38			7.65			15.67	

Table 3.9 Estimates of the parameters for each shoot in Station L3 (Figure 2.1) at 15 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L3-15m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	382.18	36.78	0.00	48.34	12.39	0.00	4.89	0.07	0.00	-45.62	4.56	0.00	585.00	0.92
2	234.02	49.18	0.00	0.22	21.64	0.99	5.10	0.12	0.00	-39.78	8.30	0.00	495.00	0.87
3	170.05	42.78	0.00	36.25	17.42	0.04	4.90	0.21	0.00	-53.21	5.99	0.00	405.00	0.73
4	185.27	42.26	0.00	-81.42	36.10	0.05	4.91	0.09	0.00	-6.25	15.07	0.69	475.00	0.96
5	58.93	22.07	0.02	70.32	17.72	0.00	1.64	0.08	0.00	0.06	6.69	0.99	420.00	0.95
6	141.26	29.87	0.00	-6.89	10.18	0.50	5.07	0.10	0.00	-21.94	3.86	0.00	485.00	0.87
7	172.64	45.79	0.00	-5.00	20.32	0.81	5.15	0.14	0.00	-25.97	7.64	0.00	375.00	0.86
8	227.56	28.70	0.00	74.61	51.74	0.19	1.05	0.05	0.00	-0.63	22.43	0.98	455.00	0.82
9	128.68	28.22	0.00	1.80	12.29	0.88	4.98	0.12	0.00	-12.11	4.61	0.01	540.00	0.99
10	131.96	20.38	0.00	10.27	9.30	0.28	5.04	0.10	0.00	-37.79	3.64	0.00	350.00	0.83
11	99.19	44.17	0.04	-68.92	25.79	0.02	4.95	0.11	0.00	49.14	9.66	0.00	410.00	0.91
12	118.25	26.67	0.00	-8.84	7.62	0.25	5.06	0.09	0.00	-25.88	2.74	0.00	300.00	0.91
13	127.92	22.02	0.00	-4.71	7.30	0.52	5.11	0.08	0.00	-26.04	2.67	0.00	380.00	0.85
14	197.10	53.81	0.00	31.27	49.20	0.53	1.37	0.14	0.00	22.93	21.36	0.30	395.00	0.90
15	99.99	33.83	0.01	-12.01	15.47	0.44	5.09	0.15	0.00	-17.42	6.03	0.01	0.15	0.89
16	91.76	45.19	0.06	26.04	26.38	0.34	1.59	0.19	0.00	-5.17	10.49	0.63	335.00	0.81
17	79.07	58.79	0.25	222.51	112.18	0.12	0.98	0.16	0.00	65.78	49.91	0.26	320.00	0.79
18	129.40	25.82	0.00	-0.87	6.05	0.89	1.47	0.11	0.00	-16.42	2.22	0.00	455.00	0.96
19	113.41	20.43	0.00	2.00	6.90	0.77	1.79	0.09	0.00	-12.79	2.59	0.00	395.00	0.78
20	159.68	29.89	0.00	2.78	8.36	0.74	1.90	0.09	0.00	-40.37	2.98	0.00	295.00	0.89
Mean	152.41			16.89			3.60			-12.47			393.51	
SE	16.00			13.71			0.40			6.72			26.98	

Table 3.10 Estimates of the parameters for each shoot in Station L4 (Figure 2.1) at 13 meter depth with respect to Equation 9 as $y = (a1 + a2 * x) * \sin(2\pi x - b1) + (b2 + (b3 * x))$.

L4-13m	**|a1| (µm)**			**a2 (µm/year)**			**b1 (year)**			**b3 (µm/year)**			**b2 (µm)**	**R of eqn.**
shoot #	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**constant**	
1	426.56	95.71	0.00	291.44	84.38	0.00	4.75	0.25	0.00	4.94	35.15	0.89	445.45	0.75
2	207.70	45.67	0.00	-25.72	27.61	0.36	1.61	0.15	0.00	-66.75	11.02	0.00	565.00	0.84
3	83.24	88.80	0.40	177.22	168.71	0.35	0.99	0.27	0.00	62.30	75.30	0.45	580.00	0.90
4	178.45	77.60	0.03	-37.48	43.91	0.40	4.92	0.18	0.00	-21.87	16.58	0.20	590.00	0.78
5	190.12	42.76	0.00	-19.51	37.86	0.62	1.43	0.15	0.00	-5.40	16.37	0.75	425.00	0.91
6	351.58	66.65	0.00	-91.47	58.52	0.14	1.19	0.14	0.00	-8.84	24.19	0.72	570.00	0.90
7	112.88	42.32	0.01	-21.57	24.70	0.39	5.29	0.16	0.00	-57.82	9.38	0.00	540.00	0.81
Mean	221.50			38.99			2.88			-13.35			530.78	
SE	47.03			52.77			0.74			16.21			25.44	

Table 3.11 Comparison of mean model and combined model among themselves and with SST of the corresponding sub region.

		a1 (µm for sheath) (°C for sst)			a2 (µm/year for sheath) (°C/year for sst)			b1 (year)			b3 (µm/year for sheath) (°C/year for sst)			b2 (µm for sheath) (°C for sst)		R eqn
		Estimate	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Estimate**	**SE**	**p**	**Constant**	**SE**	
L1-15m	**Mean model**	179.89	11.37		11.64	15.14		2.69	0.39		11.73	8.01		369.50	14.68	
	Combined model	176.10	7.86	0.00	-0.43	2.02	0.83	14.20	0.03	0.00	-0.27	0.93	0.77	369.50		0.80
L2-10m	**Mean model**	193.58	10.77		-1.93	9.03		3.47	0.37		-37.61	6.12		512.75	13.02	
	Combined model	214.99	12.51	0.00	2.58	5.42	0.63	83.42	0.03	0.00	-38.12	2.26	0.00	513.00		0.84
L2-15m	**Mean model**	172.49	22.94		25.42	21.82		2.43	0.46		-17.95	11.16		463.18	26.80	
	Combined model	-203.24	18.82	0.00	4.03	8.12	0.62	111.51	0.06	0.00	-27.35	3.32	0.00	463.18		0.76
SST Reg 1		6.030	0.147	0.000	-0.005	0.012	0.700	0.901	0.012	0.000	-0.072	0.004	0.000	25.500		0.98
L3-10m	**Mean model**	159.90	7.57		-3.03	11.30		3.40	0.38		-6.06	7.65		373.00	15.67	
	Combined model	167.54	8.36	0.00	-6.53	2.75	0.02	89.63	0.03	0.00	-14.54	1.12	0.00	373.00		0.78
L3-15m	**Mean model**	152.41	16.00		16.89	13.71		3.60	0.40		-12.47	6.72		393.51	26.98	
	Combined model	159.58	9.75	0.00	-2.34	3.48	0.50	108.59	0.04	0.00	-20.76	1.46	0.00	393.51		0.75
SST Reg 2		6.037	0.143	0.000	-0.005	0.012	0.687	0.904	0.012	0.000	-0.069	0.004	0.000	25.500		0.98
L4-13m	**Mean model**	221.50	47.03		38.99	52.77		2.88	0.74		-13.35	16.21		530.78	25.44	
	Combined model	-213.39	28.41	0.00	29.26	19.05	0.13	98.96	0.10	0.00	-30.24	8.12	0.00	530.78		0.70
SST Reg 5		5.782	0.137	0.000	-0.003	0.011	0.773	0.869	0.012	0.000	-0.067	0.004	0.000	25.900		0.98

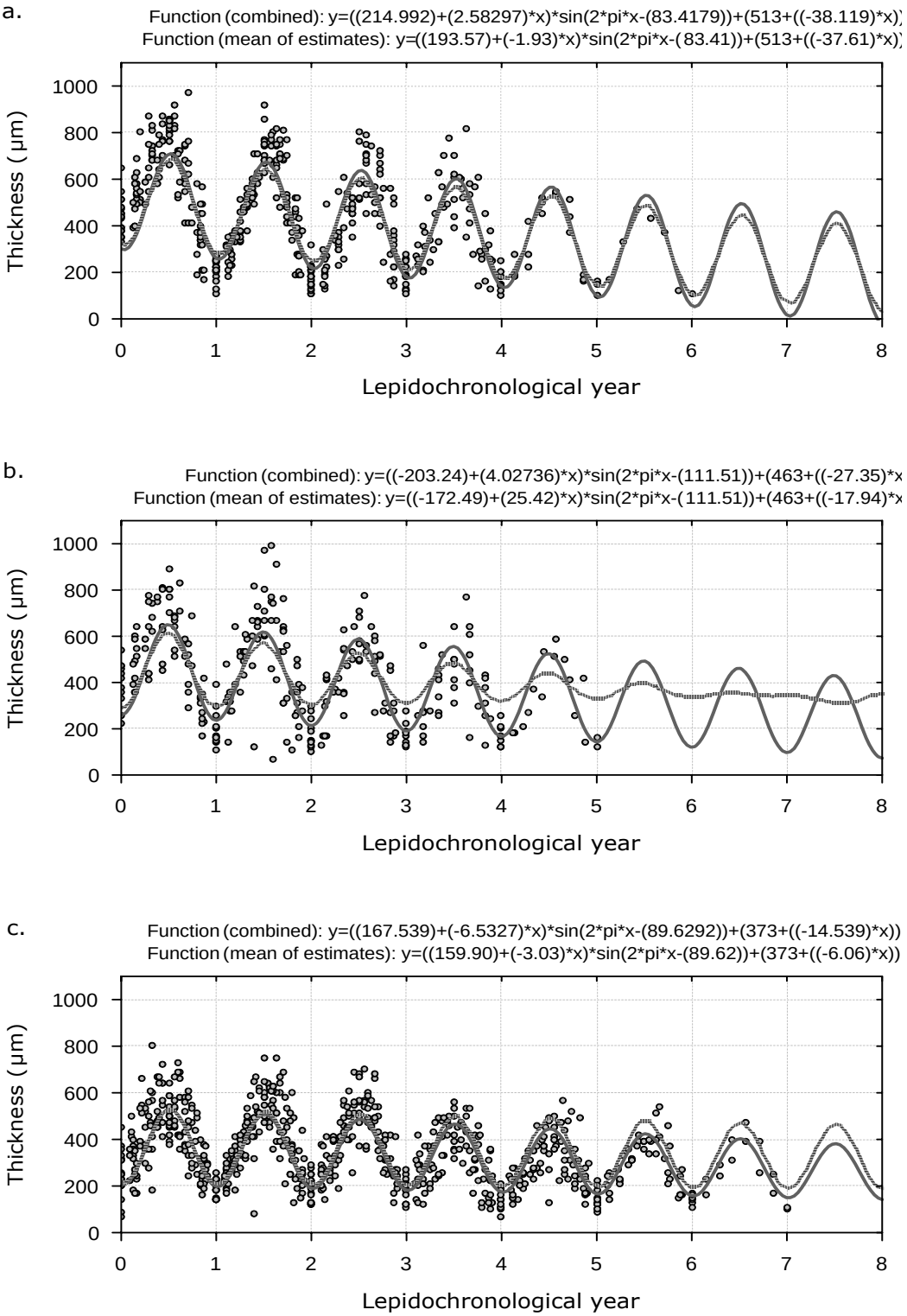
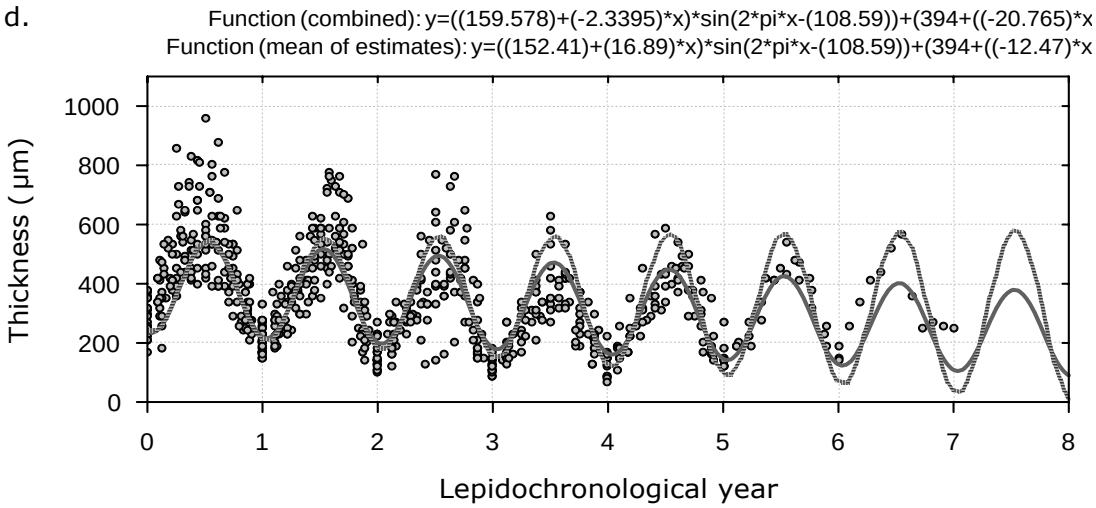


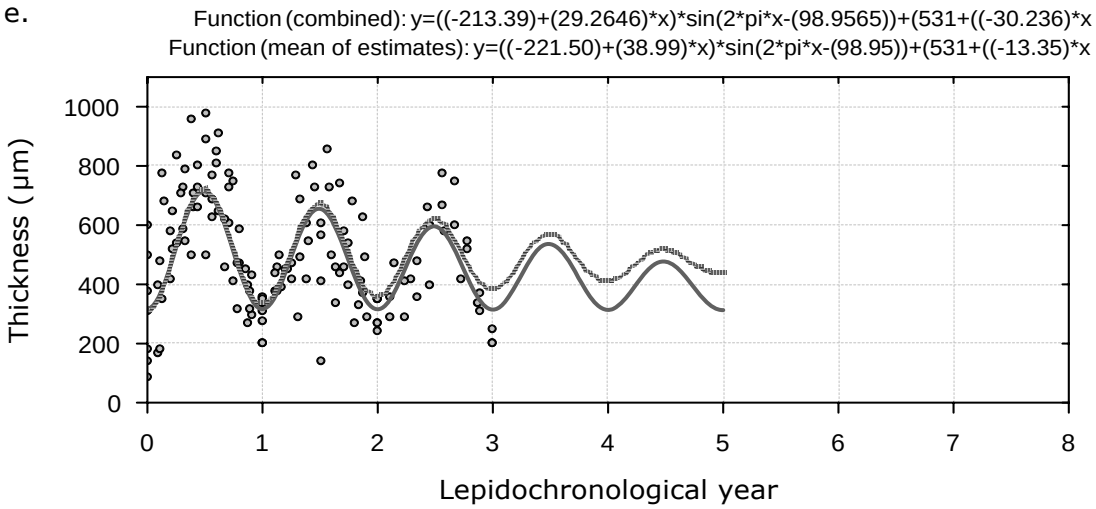
Figure 3.26 Comparison of combined model (solid line) and mean model (dotted line) with their equations.

Stations : a. L2-10m, b. L2-15m, c. L3-10m; Points are the raw data for each shoot in the station.

d.



e.



f.

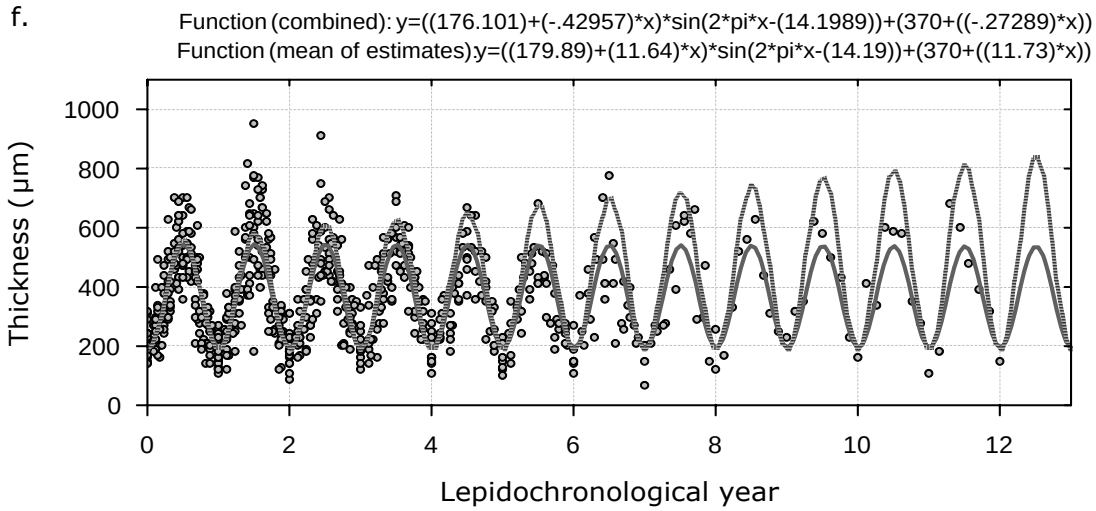


Figure 3.24 continue ; Stations : d. L3-15m, e. L4-13m, f. L1-15m.

Although the models generated for each shoot individually had higher R values, that evaluated the proportion of variance accounted for in the dependent variable sheath thickness by the model, the mean models generated from these estimates did not matched perfectly with combined models. Notably the stations L2-15m, L1-15m and L3-15m had unusual cycles. In station L2-15m the examined shoot number was less than 20. Consequently the R values for these stations in combined model were lesser than others (Table 3.10). Still the combined model was in acceptable ranges (Figure 3.27).

According to variance analysis based on mean model only estimates of a1, a2 and b2 varied significantly. And this was among the depths of stations but not among the stations which was the expected result (Table 3.12).

The application of the model to SST gave comparable results. The change of amplitude with respect to time (a2) in SST model for all sub regions were ignorable and had nearly the same value (Table 3.11). The highest warming rate (b3) was observed in region 1. This result from nonlinear regression was in agreement with the liner regression (Figure 3.28). Thus the increase of sheath thickness at this station was correlated to increase in SST in its region.

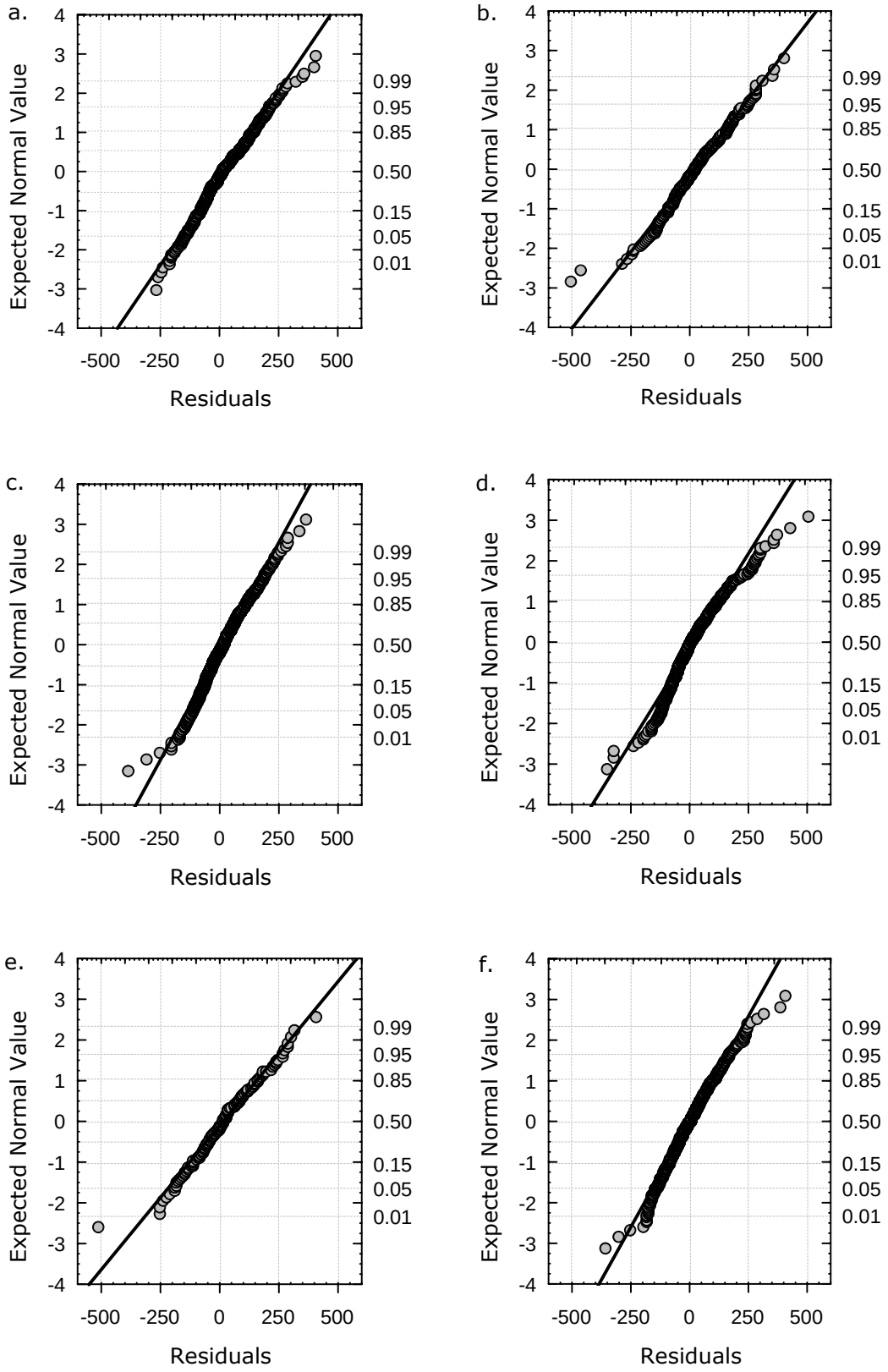


Figure 3.27 Normal probability plot of residuals in combined model.

Stations : a. L2-10m, b. L2-15m, c. L3-10m, d. L3-15m, e. L4-13m, f. L1-15m.

Table 3.12 Variance analysis of estimates from mean model in 4 stations.

* indicates significant at α=0.05

V.R. of a1	**Var1**	L2-10m	L2-15m	L3-10m	L3-15m
Var2	**n**	20	11	20	20
L2-10m	20	-	2.50 *	-	-
L2-15m	11	-	-	-	-
L3-10m	20	2.02	-	-	4.46 *
L3-15m	20	-	1.13	-	-

V.R. of a2	**Var1**	L2-10m	L2-15m	L3-10m	L3-15m
Var2	**n**	20	11	20	20
L2-10m	20	-	3.21 *	1.57	-
L2-15m	11	-	-	-	-
L3-10m	20	-	-	-	1.47
L3-15m	20	-	1.39	-	-

V.R. of b1	**Var1**	L2-10m	L2-15m	L3-10m	L3-15m
Var2	**n**	20	11	20	20
L2-10m	20	-	1.62	1.20	-
L2-15m	11	-	-	-	1.10
L3-10m	20	-	-	-	1.48
L3-15m	20	-	-	-	-

V.R. of b3	**Var1**	L2-10m	L2-15m	L3-10m	L3-15m
Var2	**n**	20	11	20	20
L2-10m	20	-	1.83	1.56	-
L2-15m	11	-	-	-	-
L3-10m	20	-	-	-	-
L3-15m	20	-	1.52	1.30	-

V.R. of b2	**Var1**	L2-10m	L2-15m	L3-10m	L3-15m
Var2	**n**	20	11	20	20
L2-10m	20	-	2.33 *	1.45	-
L2-15m	11	-	-	-	1.84
L3-10m	20	-	-	-	2.96 *
L3-15m	20	-	-	-	-

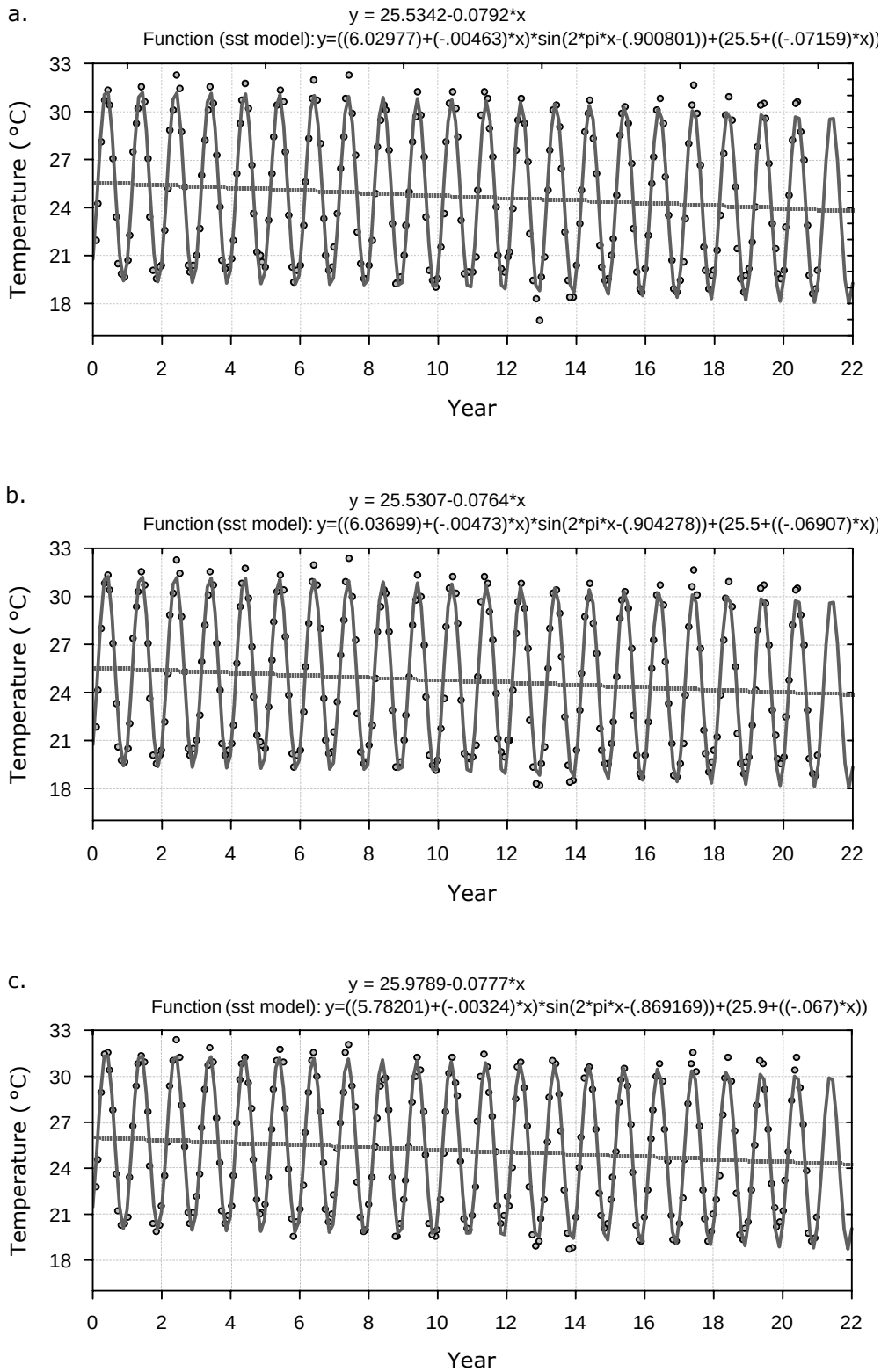


Figure 3.28 Nonlinear model of SST in sub regions.

Stations: a. Region 1; b. Region 2-3; c. Region 5. The nonlinear model (solid line) and the linear regression (dotted line).

Phenological analysis; carried on the collected shoots added more information about the leaving part of the meadows. Some of these parameters were also monitored through in-situ observations (see Section 3.2). The results were summarized in Table 3.13.

Shoots in station L1 and L4 (Table 3.13) had more adult and juvenile leaves than intermediate leaves. But the stations L2 and L3 (Table 3.13) had more intermediate leaves. The station L4 (Table 3.13) had very high percentage of coefficient A for both adult and intermediate leaves among all the other stations. In other stations only adult leaves were grazed by herbivores or broken due to wave actions.

In all stations adult leaves had higher mean leaf length and mean leaf width than intermediate leaves. In stations L2 and L3 (Table 3.13) at 10 meter depth the intermediate leaves had higher photosynthetic leaf area index than adult leaves whereas at 15 meter depth this was the opposite.

The leaf widths of both adult and intermediate leaves were wider in station L3 than L2 (Figure 3.29). Both adult and intermediate leaf lengths increased with increasing depth in L3 but decreased in L2. These were confirming the results obtained from meadow parameters (Figure 3.23; L3 $\rightarrow$ M6, L2 $\rightarrow$ M3).

Table 3.13 Phenological measurements classified according to leaf type.

Results were given with 95% confidence interval, LAI: Leaf Area Index.

Leaf Type	Phenological Parameters	Station / Depth	L1 (Figure 2.1)	L2 (Figure 2.1)	L3 (Figure 2.1)	L4 (Figure 2.1)
ADULTL	Mean Number of leaves / shoot	10m		1.95 ± 0.34	1.76 ± 0.47	
		15m	2.50 ± 0.44	1.82 ± 0.36	3.25 ± 0.42	2.13 ± 0.69
	Coefficient A / shoot (%)	10m		15.87 ± 0.12	1.67 ± 0.03	
		15m	50.88 ± 0.13	16.67 ± 0.19	15.17 ± 0.09	92.71 ± 0.09
	Mean Leaf Length (mm)	10m		256.90 ± 23.11	199.38 ± 22.23	
		15m	318.02 ± 39.03	239.60 ± 31.64	217.26 ± 16.72	92.65 ± 18.39
	Mean Sheath Length (mm)	10m		24.49 ± 4.15	18.67 ± 2.87	
		15m	29.46 ± 2.42	19.70 ± 6.40	23.57 ± 2.36	19.53 ± 2.22
	Mean Leaf Width (mm)	10m		7.88 ± 0.20	8.23 ± 0.32	
		15m	9.06 ± 0.15	7.85 ± 0.36	8.88 ± 0.15	7.71 ± 0.42
	Leaf Area Index / shoot (cm^2)	10m		39.88 ± 9.45	31.03 ± 10.64	
		15m	76.01 ± 16.82	34.74 ± 10.99	62.84 ± 11.06	15.59 ± 6.67
	Leaf Area Index (Photo.) / shoot (cm^2)	10m		36.06 ± 8.76	28.11 ± 9.67	
		15m	68.99 ± 15.72	31.80 ± 9.78	56.43 ± 10.57	12.38 ± 5.66
	Primary production of blade (mg/shoot)	10m			356.96 ± 65.22	
		15m	775.50 ± 106.79	425.69 ± 88.25	498.49 ± 55.65	92.57 ± 22.93
	Primary Production of sheath (mg/shoot)	10m			71.24 ± 19.60	
		15m	163.03 ± 29.11	51.46 ± 14.44	132.99 ± 26.06	231.66 ± 92.36

Table 3.13 continue.

Leaf Type	Phenological Parameters	Station / Depth	L1 (Figure 2.1)	L2 (Figure 2.1)	L3 (Figure 2.1)	L4 (Figure 2.1)
INTERMEDIATE	Mean Number of leaves / shoot	10m		2.90 ± 0.30	2.62 ± 0.32	
		15m	1.40 ± 0.26	2.64 ± 0.40	2.75 ± 0.24	0.63 ± 0.36
	Coefficient A / shoot (%)	10m		1.59 ± 0.03	1.59 ± 0.03	
		15m	0.00 ±	0.00 ±	1.67 ± 0.03	20.00 ± 0.39
	Mean Leaf Length (mm)	10m		195.33 ± 22.62	154.53 ± 19.03	
		15m	88.79 ± 11.69	145.62 ± 30.23	173.00 ± 18.55	68.40 ± 9.83
	Mean Leaf Width (mm)	10m		6.98 ± 0.13	7.59 ± 0.22	
		15m	8.64 ± 0.24	7.33 ± 0.23	8.28 ± 0.15	7.80 ± 0.24
	Leaf Area Index / shoot (cm^2) [= LAI (Photo.) / shoot (cm^2)]	10m		40.46 ± 6.47	30.53 ± 7.55	
		15m	10.73 ± 2.52	28.83 ± 10.23	39.81 ± 6.39	5.35 ± 0.88
JUVENILE	Mean Number of leaves / shoot	10m		0.76 ± 0.23	0.86 ± 0.15	
		15m	2.50 ± 0.30	0.91 ± 0.18	0.95 ± 0.27	2.13 ± 0.69
	Mean Leaf Length (mm)	10m		21.56 ± 8.69	20.50 ± 8.17	
		15m	16.28 ± 4.08	15.10 ± 7.36	13.00 ± 6.14	14.94 ± 6.33
	Mean Leaf Width (mm)	10m		5.50 ± (n:1)	7.18 ± 0.46	
		15m	7.88 ± 0.45	- ± -	8.00 ± (StDv=0)	7.80 ± 0.39

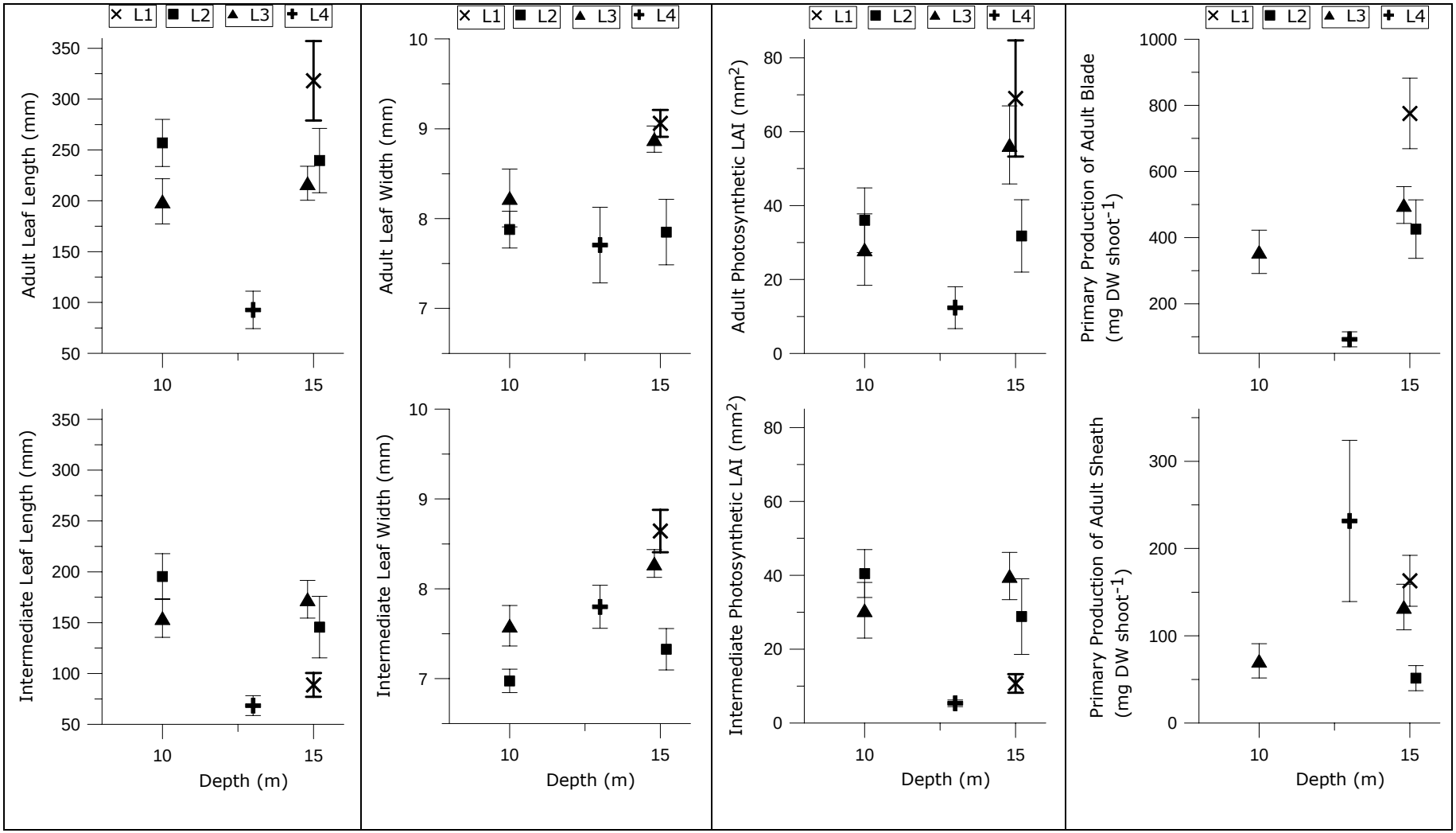


Figure 3.29 Changes of leaf parameters with respect to depth in all stations.

3.4 Transplantation

Parallel to the investigations about the natural meadows and their interactions with physical environment the restoration experiment was completed. For that purpose, totally 22 frames were transplanted in 3 different stations. At the end of the study period, there were only 13 frames with alive *Posidonia oceanica* cuttings, whereas other frames failed due to different reasons.

The first two frames F1 and F2 transplanted in December 2004 to station T3 were found demolished on a commercial purse-seiner boat just after 10 days of their transplantation date (Figure 3.30 a.). Likewise the frame F10 was damaged by trawlers, although the frame was protected against mechanical damages by an iron cage (Figure 3.30 b.). The trawlers also caused to lose the temperature logger at 10 meter depth in station H4 (Figure 2.1) attached to the cage of this frame. The frame was restored in January 2006 because the *Posidonia oceanica* cuttings were still alive and healthy.

a.  b. 

Figure 3.30 Damaged frames of transplantation experiment.

a) frames F1 and F2 found on commercial purse-seiner boat,
b) frame F10 at station T2 destroyed by bottom trawling.

The cuttings on frames F3 and F4 transplanted to station T2 (Figure 2.1) on May 2005 were found dead on July 2005 (Figure 3.31 a.). The possible reasons for this situation included the high seawater temperatures, low light penetration or pathogens that might affected the *Posidonia oceanica* cuttings during transportation between collection and transplantation sites. Therefore the frames were collected and reattached with new *Posidonia oceanica* cuttings to retry the

transplantation experiment in station T2. The frame F5 transplanted to a depth of 13 meter was found overgrazed after one month of its transplantation date (Figure 3.31 b.).

a.  b. 

Figure 3.31 Frames with transplanted *Posidonia oceanica.*

a) frame F3 at station T2 (Figure 2.1), 2 months after transplantation;
b) frame F5 at station T2 (Figure 2.1), 1 month after transplantation.

The frame F7 transplanted to inside the harbor of the institute in station T2 (Figure 2.1) to detect the grazers and their potency for overgrazing was exposed to the same herbivorous pressure. This grazing activity was monitored and proofed further with the camera system. The basket with *Posidonia oceanica* cuttings was a little elevated from the bottom to inhibit the Indo-Pacific conch, *Conomurex persicus,* to climb up the shoots. During the monitoring period the leaves were attacked only by *Siganus* species. Other species used the artificial patch either for hiding, e.g. *Fistularia sp*. camouflaged between the leaves, or for hunting.

The aquarium systems proved much more information about the behavior of Indo-Pacific conch. In both of the trials in the aquarium only vegetated by *Posidonia oceanica* cuttings, the conchs buried themselves to the sand and died after one month (Figure 3.32), whereas they survived in the control aquarium by feeding either on algae on small stones or detritus.

Finally, the last 12 frames (F12-22) in station T3 (Figure 2.1) and frame F8 in station T1 (Figure 2.1) were still alive in October 2006. *Posidonia oceanica* cuttings attached to the F9 in T3 (Figure 2.1) survived longer than 1 year after

their transplantation and the response of the transplanted cuttings to the changes in environmental conditions were observed in lepidochronological analysis of 7 sample cuttings taken from this frame in October 2006 (Figure 3.33 a.).

Figure 3.32 Indo-Pacific conch, *Conomurex persicus,* in the aquarium with *Posidonia oceanica* vegetation.

The high grazing pressure on the leaves of cuttings in this transplantation site noticed in phenological analysis was also confirmed by in-situ observations. During the control dive in September 2006, beside the herbivorous lessepsian *Siganus sp.* attacking the leaves of transplant cuttings some other Atlanto-Mediterranean fish species, e.g. *Coris julis*, *Xyrichthys novacula*, were visually recorded over the frames.

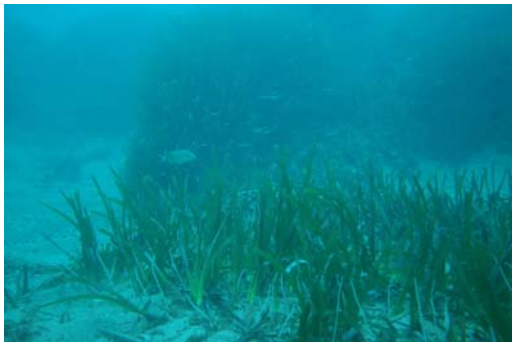
a.  b. 

Figure 3.33 Transplanted *Posidonia oceanica.*

a) F9 at station T3 (Figure 2.1), 8 months after transplantation;
b) The control frame F8 at station T1 (Figure 2.1), 3 months after transplantation.

To conclude, the survival of the *Posidonia oceanica* cuttings in station T1 longer than 8 months (Meinesz, 1991) showed the success of the methodology used for transplantation (Figure 3.33 b.).

4. DISCUSSION

The *Posidonia oceanica* (L.) Delile is a temperate seagrass inhabiting the warm waters of the Mediterranean Sea (Hemminga and Duarte, 2000). The beds of this plant form cover a surface area of 25.000-50.000 km^2 in Mediterranean Sea, thus representing 1-2% of the seafloor (Pasqualini *et. al.*., 1998). By forming complex systems they alter their environment (Mateo *et. al.*., 1997), but also affected by their environment (Larkum *et. al.*, 2006). Accounted to this reciprocal interaction, there are differences in their distribution and population dynamics along the Mediterranean coasts (Green and Short, 2003). Within this preliminary study carried out at the most extreme end of the eastern Mediterranean Sea, the interaction between the hydrological properties of sea water and *Posidonia oceanica* meadows were discussed below. Further the reasons of the absence of these meadows at the far end of the north eastern Mediterranean Sea is hypothesized in the forthcoming and tested lastly using transplantation technique.

4.1 The distribution and state of *Posidonia oceanica* meadows in north eastern Mediterranean Sea

There are many studies investigating the distribution of western Mediterranean meadows for monitoring and mapping (Leriche *et. al.*., 2004; Pasqualini *et. al.*., 1998; Pasqualini *et. al.*., 2005). The result of these studies showed that the western distributional limit of *Posidonia oceanica* in Mediterranean is set by the Almeria-Oran density front; located 250 km eastward from Gibraltar strait (Marba *et. al.*. 1996). On the other hand the information about the distribution in eastern part of the Mediterranean is sparse (Borum *et. al.*, 2004). In the eastern Mediterranean Sea the distributional limit is situated more eastwards along northern coasts than in African coast and they are not recorded along Lebanon, Israel and Syria (Larkum *et. al.*, 2006). Thus the meadows were supposed to end somewhere along the Turkish coasts. Additional to geographical limits there is a depth limit for *Posidonia oceanica* meadows influenced by environmental conditions. This range changes generally from 0.5 to 40 m, but there were

records of living plants even at 48 m (Larkum *et. al.*, 2006). In turbid waters the limit decreases up to 9 m (Pergent *et. al.*., 1995, cited in Larkum *et. al.*, 2006). According to previous studies for eastern Mediterranean the depth limit was finishing at 35m (Mihai, 1985).

Thus, this study confirmed both the eastern distribution limit and low depth limits in southern Turkish coasts. The eastern boundary was found at station M6 (Figure 2.1) with a maximum of 19 m depth. This was approximately 9 km west of the records in 1986 by Cirik. Likewise there were early records of regression of *Posidonia oceanica* meadows in eastern Mediterranean (Bellan, 1985). In other meadows located western of this boundary inside the study area, the maximum depth limit was recorded at 31.8m. Those meadows had also higher shoot densities than the boundary meadow (Table 3.3).

As both limits are changing with the physical and chemical properties of seawater, within the biological range of the species defined by its genetic, the present study looked for the differences and changes in environmental conditions. The outcomes proposed different possible causes for the absence and/or disappearance of *Posidonia oceanica* meadows in north eastern Mediterranean along the Turkish coasts. These can be clustered to 2 general headings; natural hindrances and anthropogenic impacts.

For the study area, temperature and light conditions were presumed to be the most effective natural hindrances. According to theoretical seagrass depth limit calculated from light data in August 2005 (Figure 3.15) there might be only one suitable area located on eastern side of the boundary with shallower depths (<50m). This area was located along the northwestern coasts of the Iskenderun Bay, but which exhibited also the highest temperatures (Figure 3.2) during the same season (>28°C). So when light penetration was optimized, the high temperature became limiting. In literature, this location was cited for the presence of *Posidonia oceanica* meadows (Tutin, 1964; c.f. UNEP-WCMC Species Database in URL 7), but today there were no meadows found there. Thus, it points out again the possible regression of meadows from the area due to changing environmental conditions in eastern Mediterranean (Goren and Galil, 2005).

Another evidence for natural hindrance was driven from the transplantation experiment. The Iskenderun and Mersin Bays have very shallow continental shelves which are exposed to high mixing. In station T2 (Figure 2.1), which is under the effect of mixing during all year (Bayındırlı, 2007), the transplants could not survive. On the other hand the *Posidonia oceanica* zone and the region 5 (Figure 2.1), which was chosen for transplantation experiment, have sharp steepness. This geomorphologic difference among the Levant basin can affect the hydrodynamic structure of the water column which in turns defines the *Posidonia oceanica* distribution, partially.

The same bays were also under the increasing pressure of human population. The settlement, tourism and industrial development in these areas caused eutrafication (Galil and Zenetos, 2002). Additionally the increasing fishery activities mainly based on bottom-trawling and purse-seining (Gücü and Gücü, 2002) damaged the bottom vegetations. The *Posidonia oceanica* shoots in natural meadows, and even the transplants, were exposed to this threat during the study period. As the loggers in station H4 (Figure 2.1) were lost and the frame F10 in station T2 (Figure 2.1) was damaged by the trawling activity in forbidden areas at such shallower depths (10m), the regression of the meadows in the study area might be also imputed to mechanical damage in considerable degrees.

The last phenomenon to pay attention when considering the changes of seagrass distributions is the climate changes (Borum *et.al.*, 2004). These include global warming, sea level rising, increase of carbon dioxide and increasing strength of storms, which are induced indirectly by anthropogenic effects. From these changes, the global warming has a special importance for the eastern Mediterranean. It can indirectly produce an increase of storm events, which will result in increased coastal erosion and sediment resuspension (Borum *et. al.*, 2004). Thus the water will be more turbid and in poorer light conditions the growth will cease. But its direct impact will be more tremendous if the global mean temperatures rise faster in the next century as predicted by the scenarios (Hemminga and Duarte, 2000). A pioneer example was observed in an oceanic setting without pronounced human influences. The gradual decline in *Zostera marina* beds during 1980s and 1990s were related to elevated sea-surface temperatures (Glemarec *et. al.*., 1997).

For predicting the specific impacts of the temperature increase much more research is required. Still, the direct effect of increased temperature will obviously depend on individual species' thermal tolerance and on the specific temperature dependency of the many processes determining the growth and reproduction (Short and Neckles, 1999). For species living near their upper temperature limit, a further increase in temperature may be fatal. This may be accounted for the disappearance of *Posidonia oceanica* meadows in north eastern Mediterranean in Turkish coasts. Given the present study, along the region 5 in station T3 (Figure 2.1) the transplants were exposed to temperatures higher than 28°C, while the tolerable temperature range of *Posidonia oceanica* is between 9-29°C (Boudouresque and Meinesz,1982; c.f. Larkum *et. al.*, 2006).

In less critical environments, increasing seawater temperature may have an impact on processes like photosynthesis, respiration, nutrient uptake, flowering and seed germination (Short and Neckles, 1999). From these general responses, increased flowering density were observed in *Posidonia oceanica* meadows in western Mediterranean and linked to the temperature rise (Diaz-Almela *et. al*., 2007). In the present study same data set from NOAA, but with a different processing method, was used to parallelize the temperature changes in eastern Mediterranean with western Mediterranean found in the Almela's publication. The years of flowering were not consistent, because the warming in eastern Mediterranean was not in the same years. But the response due to high temperature was similar. In eastern Mediterranean the flowering was recorded for station L1 (Figure 2.1) in 1999 and 2004 just after the hot summers in 1998 and 2003.

To conclude, such effects of climatologically changes will have consequences for competitive ability of seagrass populations and therefore it will alter seagrass distribution and abundance in long term (Hemminga and Duarte, 2000).

4.2 The interaction of environmental and biological parameters of *Posidonia oceanica*

Physical environment, as discussed in the previous section, has both large and small scaled impacts on seagrasses (Short and Coles, 2001). In global perspective they influence the geographical distribution of seagrasses and speciation. On the other hand local effects can be monitored through morphological (e.g. leaf biometry) and physiological (photosynthesis, respiration) differences among meadows of the same species. In this study only main physical characteristics of the sea water were considered, namely temperature, salinity and light. Additionally basic sedimentological classification was included. The results were than related to the structural and functional descriptors of *Posidonia oceanica*.

The 5 regions in the study area (Figure 2.1) differentiated generally speaking in temperature and light conditions. The vertical profiles of salinity showed similar and stable results (Figure 3.10 and 3.10). *Posidonia oceanica* is a stenohaline species, meaning not to able to tolerate salinity fluctuations, and it is not present when the salinity is below 33 psu (Larkum *et. al.*, 2006). In the study area the salinity ranged between 38.4-39.6 psu, which is in tolerable growth range of *Posidonia oceanica.* Due to the osmotic stress, high and low salinities can lead from loss of functionality to necrosis ending up with death (Hemminga and Duarte, 2000). Thus the *Posidonia oceanica* meadows disappear near big river mouths (e.g. Rhone, Po and Nile) due to input of fresh water decreasing the salinity and additional high loads of fine sediments decreasing light penetration (Pergent *et. al.*., 1995, c.f. Larkum *et. al.*, 2006).

For sedimentological analysis an exact interdependency between the presence of *Posidonia oceanica* meadows and sediment type could not be determined. Most of the stations were composed of slightly gravelly muddy sand during the two successive years of the study period (Table 3.2). But the higher muddy ratio in station G5 at the deep limit of boundary meadow was remarkable due to its impact on light penetration. When the light level decreases it causes the plants to prolong the leaves and to thin the shoot density (Borum, 2004). With this acclimatization the plant can capture more light to convert it to photosynthetic production. This explains the increase of canopy height (Figure 3.23) and parallel decrease of shoot density (Figure 3.22) in station L3-15m (Figure 2.1) compared

to L3-10m. The increasing leaf parameters were also confirmed by lepidochronological analysis (e.g. the increasing leaf length, leaf width and leaf area index calculated from these two; Figure 3.29).

Contrarily to the grain size, the geochemical results of sediments (Figure 3.21) can be inferred that there is a relation between the calcium carbonate percentages in the sediment and *Posidonia oceanica* meadows, which inhabit numerous calcareous organisms both in matte structure and on leaves as epiphytic organisms (Havelange *et. al.*., 1997). The first two regions occupied by *Posidonia oceanica* meadows had $CaCO_3$ percentages higher than 50%. Another feature of the $CaCO_3$ analysis is that it addresses the geochemical factors determining nutrient availability in pore water (Short and Coles, 2001). Seagrasses affect $CaCO_3$ metabolism by means of enhancing both; carbonate dissolution in sediments and carbonate precipitation by associated epibionts (Larkum *et. al.*, 2006). For carbonate dissolution CO_2 is required, which is generated through the aerobic mineralization of organic matter. This process is enhanced via seagrass beds due to deposition of organic matter and the O_2 release from roots and rhizomes. Carbonate dissolution due to seagrass beds in turn increase phosphate concentration in pore water (Burdige and Zimmerman, 2002). Because significant fraction of phosphorus is adsorbed to carbonate minerals, it can only be available to the plant by this acid dissolution. Therefore the phosphate availability for uptake by seagrasses, and thus the seagrass production (Romero *et. al.*., cited in Larkum *et. al.*, 2006), can be increased via enhanced sediment carbonate dissolution. Additionally precipitation of $CaCO_3$ in seagrass beds due to calcifying organisms increase concentration which stimulate photosynthesis (Gacia *et. al.*, 2003). Therefore carbonate precipitation might supply significant fraction of inorganic carbon to support high seagrass productivity in carbonate environments. So the relative higher $CaCO_3$ concentrations in the first two regions compared to non-*P. oceanica* regions can be attributed to this metabolism. Even the % $CaCO_3$ in station G6 (Figure 2.1), where no meadows are present anymore, can be a clue for the regression of *Posidonia oceanica.* The presence at this station in the past was supported by records of Cirik in 1986. This was a 20 year old record going back from today. During this period considerable increase in fishing fleet were observed in this area (pers comm. F. Bingel). Thereof another possible cause of regression from this site might be sought in the increased fishery activity.

As pointed out in distributional evaluations the light and temperature play the critical role in the growth and survival of seagrasses. Thereof the present study attributed their effects on phenological and lepidochronological results due their ability for proving long term variations. The light penetration showed variations both in time and spatial scales in the study area (Figure 3.14 to Figure 3.18). Inside the bays of Mersin and Iskenderun the calculations of theoretical depth limits demonstrated the unsuitability of the environment. This was expected for the bays because they are under the negative anthropogenic impacts, however further calculation based on Duarte's formula gave unexpected findings for the *P.oceanica* zone (Figure 3.19). The ratio of theoretical depth to real depth nearly in all station was found lower than 1, which means that the 10% of surface irradiance does not reach to the bottom. Under this circumstance all meadows in the study area are suspected to decline. In such a case the first response is the regression of lower depth limit, decreasing shoot density and increasing leaf length with depth (Borum, 2004). All these were recorded only for station M6 (≡L3) at the boundary meadow and M2 (Figure 2.1), but not in other meadows (Table 3.3).

Other differences in lepidochronology among stations were attributed to temperature. The most obvious difference among stations for temperature was observed in setup 1 period when the percentages of exposure to Maximum Tolerable Temperature Limit value were considered. The reason, that the calculation of Maximum Tolerable Temperature Limit value was based on the data set at the station H1 (Figure 2.1), was the healthy meadows present there, being enclosed and conserved in a marine protected area. They have been assumed to show normal values of growth parameters and thus capable of tolerating the temperature they were exposed to. East to that station there was only one station with *Posidonia oceanica* meadow (H2) having higher temperatures than Maximum Tolerable Temperature Limit. All the other 3 eastern stations without *Posidonia oceanica* meadows showed much higher percentage of exposure to temperatures higher than Maximum Tolerable Temperature Limit. The importance of differences in exposure times to higher temperatures was attributed to the effect of temperature on the balance between photosynthesis and respiration rates (Dawes, 1998).

This difference in temperature was also not limited only to this study period but in general the eastern part of the study area was warmer than western regions. This was supported through the evaluation of sea surface temperature taken from the long term satellite data. And the combination of this long term temperature observations with biological responses of *Posidonia oceanica* through the lepidochronology proved to be an effective tool for analysis of changes in eastern Mediterranean. The model fitted to both basic sinusoidal cycles in temperature and lepidochronology attempted to include additional variables to differentiate between stations. However the bias in both of the models was the elimination of anomalies in cycles, which could occurred due to abrupt changes in environmental conditions, such as flowering related high sea water temperature episodes (Diaz-Almela *et.al.*, 2007). Still the difference in amplitude (a1) and the faster vertical shift change rate (b3) in station M3 caused to suspect whether the temperature at this station is not limiting but enhancing the growth because it is not at the end of the tolerable range. On the other hand station M6 (Figure 2.1) may be experiencing inhibiting temperature effect due to consistent high temperatures.

The mentioned variations of environmental and biological descriptors were summarized below in Table 4.1 only for two stations M3 and M6 (Figure 2.1). At these stations, one representing healthy meadows in a protected area and the other at the boundary meadow, all descriptors were measured. So this gave the outline of the study area. There are different responses both with respect to depth and stations. According to comparison of stations, from the two physical parameters light penetration increased when going from east to west, whereas temperature decreased. Parallel to the increase in light most of the parameters, except leaf formation rate and adult leaf width, increased from east to west. Thus same depths of two stations showed similar responses. Contrarily and surprisingly each station differentiated in itself with respect to their two depths. This was also confirmed by the variance analysis of lepidochronological cycle variables (Table 3.12).

Table 4.1 Summary of the parameters for station M3 (≡ L2) and M6 (≡ L3).

	AMONG DEPTHS (with increasing depth: 10m → 15m)		**AMONG STATIONS (going from east to west: M6 → M3)**	
	M3	**M6**	**10m**	**15m**
PAR (≡ theoretical depth limit)	-		Increased (general trend)	
% of time exposed to MTTL during setup 1	Increased (4.13 → 7.75)	Decreased (31.08→ 19.15)	Decreased (31.08→4.13)	Decreased (19.15→7.75)
Lower depth limit (m)	-		Increased (19.7 → 31.8)	
Meadow type	Same (HSD [843] ≡ HSD [592])	Decreased (ND [469] → LSD [208])	Increased (ND [469] → HSD [843])	Increased (LSD [208] → HSD [592])
Canopy height (cm)	Decreased (34 → 24)	Increased (36 → 41)	No comparison available due to differences in sampling seasons	
Number of sheaths (≡ leaf formation rate)	Increased (6.8 → 7.1)	Increased (8.2 → 9.0)	Decreased (8.2 → 6.8)	Decreased (9.0 → 7.1)
Rhizome length (mm)	Decreased (6.6 → 4.6)	Increased (3.5 → 4.6)	Increased (3.5 → 6.6)	Same (4.6 ≡ 4.6)
Rhizome weight (mg)	Decreased (43.5 → 23.6)	Increased (21.5 → 23.5)	Increased (21.5 → 43.5)	Same (23.5 → 23.6)
Amplitude (a1) from mean model (µm)	Decreased (193 → 172)	Decreased (159 → 152)	Increased (159 → 163)	Increased (152 → 172)
Amplitude change (a2) from combined model (µm/year)	Increased (2.58 → 4.03)	Decreased (-6.53 → -2.34)	Increased (- → +)	Increased (- → +)
Vertical shift (b2) from mean model (µm)	Decreased (512 → 463)	Increased (373 → 393)	Increased (373 → 512)	Increased (393 → 463)
Vertical shift change (b3) from mean modal (µm/year)	Decreased (-37 → -17)	Increased (-6 → -12)	Increased (-6 → -37)	Increased (-12 → -17)
Vertical shift change (b3) for SST data (µm/year)	No data for comparison between depths		Increased (-0.069 → -0.072)	
Adult leaf length (mm)	Decreased (257 → 240)	Increased (199 → 217)	Increased (199 → 257)	Increased (217 → 240)
Adult leaf width (mm)	Same (7.88 ≡ 7.85)	Increased (8.23 → 8.88)	Decreased (8.23 → 7.88)	Decreased (8.88 → 7.85)
Adult photosynthetic LAI (cm^2)	Decreased (36 → 31)	Increased (28 → 56)	Increased (28 → 36)	Decreased (56 → 31)

4.3 The success of *Posidonia oceanica* transplantation experiment

The global loss of seagrass meadows increased the attention to restore the lost meadows due their resource value to ecosystem and to human usage (Genot *et. al.*., 1994; Van Katwijk *et. al.*., 1998; Balestri *et. al.*., 1998; Molenaar *et. al.*. 1992, 1993 and 1995). For creating a seagrass meadow, transplantation of plant material from existing meadows were used until now (Hemminga and Duarte, 2000). These materials could be either seeds or shoots with roots and rhizomes. Though the planting of seeds look more conservative and easy it was much less frequently applied due to a variety of reasons. In some species seeds are difficult to obtain whereas in other the seed viability and seedling survival is very low. In the present study shoots from donor meadows located west to the boundary meadow were used, because no flowering and/or seed production was observed during the study period. Also the time interval for the restoration activity, purposed to test the suitability of the environmental conditions, was too limited to risk the survival of seeds if any could be found.

The survival of transplanted unit is very highly variable and determined by many different factors (Fonseca, 1994; c.f. Hemminga and Duarte, 2000). However the most crucial one is transplantation site. According to Fonseca the environmental conditions of transplant site should approach those at donor meadow and the transplant site should have supported seagrass in the past. And if the site was previously occupied by the same seagrass but then due to deterioration of environmental conditions it disappeared there, than the cause should have removed from the system. During this study, not all of these optimal conditions were met, because the first aim of the transplantation was not to recover but to test the suitability of the area for this species. According to the survival of transplants it could be predicted whether the meadows once present in eastern Mediterranean have disappeared due to rapid destructive effects of human (e.g. fishery, eutrafication etc.) or due to long time changes in the ecosystem (e.g. climate changes, removal of the nutrient reach water from Nile river, Lessepsian migration etc.)

During this study, first priority was given to the substratum, its coverage and depth. In region 5, the transplantation site T3 (Figure 2.1) was chosen due the coverage of seahorse grasses, *Cymodocea nodosa*, which is pioneer species in the succession of seagrass communities in Mediterranean (Den Hartog, 1971;

c.f. Hemminga and Duarte, 2000). However, according to Den Hartog, the reef forming *Posidonia oceanica* dies when it develops mounds reaching close to water surface which are then colonized by *Cymodocea nodosa*. Thus the succession sequence is not unidirectional but may be reverted or short-circulated by disturbance. The observations of *Cymodocea nodosa* during the study period in areas, where *Posidonia oceanica* have regressed, can be related to this succession cycle.

The most critical time after transplantation was the first year, because the cuttings must acclimate and establish roots during this interval (Balestri *et. al.*., 1998). Thereof the best strategy was supposed to plant just after the period of highest seasonal stress when also natural populations show recovery (Short and Coles, 2001). But there were different suggestions for the best time of transplantation according to the geographical regions. To rescue from autumn and winter storms, it was suggested in late winter (Borum *et. al.*, 2004). Then from February to May they can grow actively producing root to anchor into the sediment. On the other hand for western Mediterranean it was found by Meinesz *et.al.*. (1992) that mortality of the cuttings was highest for transplants made in early summer, when temperatures exceeded 20-degrees-C, and lowest for those made in autumn.

In this study first transplantation was made in winter 2004 but it could not be monitored for long time because it was destroyed by trawlers immediately. The next two frames F3 and F4 (Figure 3.31), transplanted in late spring, were found with dead brown leaves. It was possibly that the increasing seawater temperature caused stress and therefore did not allow enough time for adaptation of transplanted cuttings. Increasing temperature might have also an impact on the infection of necrosed part of the cuttings. The frames F8 and F9, which were transplanted in autumn as supposed for *Posidonia oceanica*, were the longest surviving transplants. And the lepidochronology of the shoots taken from frame F9 (Figure 3.24, rhizome length and weight at station L4) showed higher rhizome production than other stations. This difference recorded for transplanted cuttings can be an adaptation to the new habitat for settling and expanding. But still, one year of survival after transplantation is a very short time to evaluate the real response of *Posidonia oceanica* cuttings.

Lastly, the success of the transplantation for this study was noticed through the associated fauna. In their natural environment seagrass meadows inhabit many animals. Thus they were not just vegetation covering the sea bottom but an ecosystem with high biodiversity (Hemminga and Duarte, 2000). Several studies showed that transplanted plants forming a new seagrass bed are colonized by many animals (Fonseca *et.al.*., 1990 and 1996). However the composition and abundance of the newly established community depends on the successful development of the new bed. During the study period above the frames in all stations, both Lessepsian and Mediterranean fish species were observed. The fauna/flora of the transplants was not only limited to fish species but also indo-pacific conch, fire worm and epiphytic organisms were visualized during control dives. However the strange scene in station T2 (Figure 2.1) was the shortening of leaves possibly due to grazing.

Grazing of seagrass is highly variable in time and space (Hemminga and Duarte, 2000). The rates of consumption may be negligible or higher than production, which leads to complete defoliation of the vegetation. Thus the pressure of grazing is determined both from the abundance and composition of herbivore community. Another variability is induced by the fact that not all seagrass species are equally appreciated due to the difference in leaf property. As outlined by Cebrian and Duarte (1998) the leaves of species with high specific growth rate are preferred because they have higher palatability related to lower contents of indigestible lignin-cellulose compounds. Such examples include *Cymodocea sp.* and *Halophila sp.* while *Posidonia oceanica* is not so much favored. Thus *Posidonia oceanica* appears to be a minor food source though its important biomass in Mediterranean (Dauby,1989; c.f. Larkum *et. al.*, 2006). Still it supports high herbivore production related to its large primary production (Cebrian *et. al.*., 1996). The high C/N ratio and hard consistency which are coupled with high encrusting rate by calcareous epiphytes make the leaves difficult to be assimilated by grazers (Havelange *et. al.*., 1997). Additionally *Posidonia oceanica* contains phenolic compounds (Agostini *et. al.*., 1998) and structural carbohydrates (Buia *et. al.*., 2000) which discourage grazing.

As opposed to Australian *Posidonia* species, no marine mammals graze in *Posidonia oceanica* meadows, only some large marine herbivores e.g. the green turtle *Chelonia mydas* in eastern Mediterranean spend 90% of its time at shallow depths ingesting seagrass (Hays *et. al.*., 2002). Other potential consumers are

the sparid fish *Sarpa salpa*, the echinoderm *Paracentratus lividus*, the isopod *Idotea baltica* and the polychaete *Platynereis dumerilli* (Larkum *et. al.*, 2006). Although the authors assumed that these herbivores are generally a minor factor in the control of *Posidonia oceanica* (Alcoverro *et. al.*., 1997; Cebrian *et. al.*., 1996; Cebrian and Duarte, 2001; Havelange *et. al.*., 1997; Pergent *et. al.*., 1997), in the present study the grazing activity was appreciated to be highly effective in transplants. The coefficient A in station L4, which gives the percentage of damaged leaves, was very high for both adult (%92) and intermediate (%20) leaves in lepidochronological analysis (Table 3.13). The difference of herbivorous strength may come out from the different herbivorous organisms in the study area. For example, in both transplantation sites T2 and T3 (Figure 2.1) the Lessepsian rabbit fish *Siganus luridus* were observed quite often attacking the leaves of *Posidonia oceanica* cuttings. Unfortunately there are not enough studies on the *Posidonia* species specific pressure of Lessepsian herbivores entered through the Suez Channel and established in eastern Mediterranean. An earlier study by Stergiou (1988) showed the successful establishment and build-up of the population of the Lessepsian migrant *Siganus luridus* in its new environment. He found *Posidonia oceanica* in the stomachs of this species beside a diverse assemblage of benthonic algae.

To conclude the transplantation methodology was applicable in eastern Mediterranean, although improvements are still needed. The study period allowed a short term monitoring of transplantation. However *Posidonia oceanica,* being a long lived species with a slow rhizome spread (0.3-2.1 cm per year), requires long time for recovery (Marba and Duarte, 1998; Marba and Walker, 1999; Paling and McComb, 2000). Thus the transplanted frames need to be monitored much longer to be evaluated for their success. But this experimental transplantation was important in two ways: i) it was the first seagrass transplantation experiment in Turkish coasts and ii) it provided a tool for the assessment of the changes in eastern Mediterranean ecosystem while contributing to monitoring of the regression.

5. CONCLUSION

This study is a preliminary work investigating the factors determining the *Posidonia oceanica* distribution in north eastern Mediterranean. Firstly the present geographical boundary of meadows in southern coasts of Turkey which is located in Mersin coasts (N 36° 09.197′, E 33° 26.801′) has been studied in detail. This boundary meadow had a lower depth limit at 19 meter and low shoot density (208) at 15 meter depth. The leaf length did increase with increasing depth which may be an indication of a stress factor. Thus, the subnormal conditions and withdrawal of meadows, which have been previously recorded eastern to that boundary, could be a sign for the regression of *Posidonia oceanica* meadows in the region. The other meadows studied on the west of the boundary had deeper lower depth limits, reaching nearly 30 meters, and higher shoot densities.

According to the outcomes of the present study the most critical factors regulating the depth and geographical limit of *Posidonia oceanica* meadows in the study area have been determined as temperature and light penetration. The eastern stations with no natural *Posidonia oceanica* meadows in the study area were exposed to temperatures higher than 28.4°C in summer months, which exceeds the upper limit of tolerable temperature range of *Posidonia oceanica*. Additionally in most of the stations the 10% of the surface irradiance could not reach the bottom even in shallow coastal stations. The changes in leaf and shoot biometry with respect to depth and station location due to these environmental differences were analyzed by lepidochronology and phenology. The alterations in leaf length and shoot density were attributed to the light conditions whereas the cyclic changes in sheath thicknesses were related to temperature. This is verified by means of a sinusoidal function.

Parallel to abiotic and biological measurements, an experimental approach to test the survival of *Posidonia oceanica* in areas where it is naturally absent was followed. For that purpose shoots collected from natural meadows were transplanted to suitable areas and monitored throughout the study period. In the first two trials the frames of transplants were destroyed by trawlers, indicating that the trawl fleet in the region might be responsible for the absence of the

plant. The leaves of the shoots in next frames were overgrazed, which pointed out the importance of herbivorous. However the final shoots transplanted to coasts of Hatay did succeed to live more than 1 year.

Lastly, monitoring of the boundary meadow and transplanted meadow need to be persuaded for future works. This may shad further lights on the changes in environmental conditions and corresponding responses of the *Posidonia oceanica* seagrass ecosystem. Thus, it is hoped that this study would be a baseline and a reference for future *Posidonia oceanica* studies in the north eastern Mediterranean.

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