ACTIONS
FOR THE CONSERVATION
OF COASTAL DUNES WITH
JUNIPERUS spp. IN CRETE
AND THE SOUTH AEGEAN
(GREECE)

LIFE07NAT/GR/000296

Action A.2
Deliverable A.2.1

REPORT ON PLANT ASSOCIATIONS COMMUNITY TYPES COMPOSITION & STRUCTURE OF COASTAL DUNES WITH *Juniperus* spp. IN CRETE

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"Actions for the conservation of coastal dunes with *Juniperus* spp. in Crete and the South Aegean (Greece)"

- JUNICOAST -

Action A.2: Determining the dune system plant communities' composition and structure

Deliverable A.2.1: Report on plant associations, community types, composition and structure of coastal dunes with *Juniperus* spp. in Crete

Responsible beneficiary: Mediterranean Agronomic Institute of Chania (MAICh)

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ΠΕΡΙΛΗΨΗ

Η διαμόρφωση των παράκτιων αμμοθινών είναι αποτέλεσμα της δράσης της θάλασσας και του ανέμου. Η βλάστηση των παράκτιων αμμοθινικών οικοσυστήματων είναι καθοριστικής σημασίας καθώς μειώνει την επίδραση του ανέμου, συγκρατεί την άμμο και συμμετέχει στην επέκταση των αμμοθινών.

Ο οικότοπος των παράκτιων αμμοθινών με είδη *Juniperus* συναντάται ακτές της Νότιας και Δυτικής Ευρώπης. Στη χώρα μας ο οικότοπος αυτός βρίσκεται κυρίως στα νησιά της Ν. Ελλάδας και αποτελεί οικότοπο προτεραιότητας στα πλαίσια του δικτύου ΦΥΣΗ 2000 (με κωδικό 2250*). Χαρακτηρίζεται ως ευάλωτο οικοσυστήμα λόγω των ακραίων οικολογικών συνθηκών (άνεμος, ξηρασία, αλατότητα, υψηλές θερμοκρασίες). Η επίδραση των συνθηκών αυτών διαμόρφωσε ιδιαίτερους τύπους βλάστησης με χαμηλή φυτοκάλυψη, μειωμένη ποικιλότητα ειδών αλλά παρουσία αρκετών ενδημικών ειδών. Προς το παρών δεν υπάρχουν αναλυτικές μελέτες που να περιγράφουν τη σύνθεση και τη δομή της βλάστησης, καθώς και τις οικολογικές διαδικασίες του οικοτόπου των παράκτιων αμμοθινών με είδη *Juniperus* στην Ελλάδα.

Στόχος της μελέτης αυτής είναι ο καθορισμός και η περιγραφή της χλωριδικής σύνθεσης και της δομής του οικοτόπου των παράκτιων αμμοθινών με είδη *Juniperus* στις 4 περιοχές της Κρήτης όπου συναντάται ο οικότοπος (Κεδρόδασος, Γαύδος, Χρυσή και Φαλάσαρνα).

Μέθοδοι

Κατα τη διάρκεια εφοαρμογής της Δράσης Α.2 έγινε τοποθέτηση 36 μόνιμων δειγματολειπτικών επιφανειών 30μ.Χ30μ. σε όλες τις περιοχές. Μέσα στην κάθε μόνιμη επιφάνεια τοποθετήθηκαν δύο μικρότερες δειγματολειπτικές επιφάνειες (10μ.Χ10μ. και 3μ.Χ3μ.) στις οποίες έγινε καταγραφή της κάλυψης και της αφθονίας των φυτικών ειδών με τη μέθοδο Braun-Blanquet (9-βαθμη κλίμακα). Επιπλέον στα όρια του οικοτόπου με άλλους αμμοθινικούς οικότοπους κοντά στην ακτή τοποθετήθηκαν τομές βλάστησης κάθετα στην ακτογραμμή και εφαρμόσθηκε η ίδια μέθοδος δειγματοληψίας (9-βαθμη κλίμακα Braun-Blanquet) σε μικρές δειγματοληπτικές επιφάνειες 5μ.Χ5μ. κατα μήκος των τομών.

Αποτελέσματα

Καταγράφηκαν συνολικά 142 είδη από 33 οικογένειες τα οποία σύμφωνα με το σύστημα Christen C. Raunkiær κατατάσονται σε 6 διαφορετικές βιομορφές. Τα περισσότερα είδη καταγράφηκαν στο Κεδρόδασος (92) και τα λιγότερα στα Φαλάσαρνα (47) ενώ στη Γαύδο και στη νήσο Χρυσή καταγράφηκαν 62 και 75 είδη αντίστοιχα. Τα αγροστώδη (Poaceae) ήταν η πιο πολυπληθής οικογένεια (14% των ειδών) και ακολουθούν τα σύνθετα (Compositae) 13.4% και τα ψυχανθή (Fabaceae) 11.3%. Οσον αφορά τις βιομορφές κυριαρχούν τα θερόφυτα (56%) και τα χαμέφυτα (16%). Σε όλες τις περιοχές καταγράφηκαν συνολικά 7 ενδημικά είδη, εκ των οποίων 4 στη νήσο Χρυσή και 3 στο Κεδρόδασος και στη Γαύδο. Η Γαύδος και η νήσος Χρυσή έδειξαν τη μεγαλήτερη χλωριδική ομοιότητα (48%) ενώ η μικρότερη παρατηρήθηκε μεταξύ Κεδρόδασους και Φαλάσαρνα (14%).

Από την ανάλυση των δεδομένων των μόνιμων δειγματολειπτικών επιφανειών (10μ.Χ10μ. και 3μ.Χ3μ.) αναγνωρίσθηκαν οι εξής 5 φυτοκοινότητες:

A1: *Juniperus phoenicea-Periploca angustifolia*

Η κοινότητα αυτή αντιπροσωπεύει θάμνους με Juniperus phoenicea συχνά σε μίξη με *J. macrocarpa*. Εμφανίζεται στη νήσο Χρυσή, σε αβαθείς ή μετρίου βάθους επίπεδες αμμοθίνες καθώς και στις μεταβατικές ζώνες με θαμνώνες. Η χλωριδική σύνθεση χαρακτηρίζεται από τη σταθερή συμμετοχή φρυγάνων και σκληρόφυλλων θάμνων (κυρίως του *Helianthemum stipulatum*), από υψηλή συχνότητα ετήσιων λιβαδικών ειδών (π.χ., *Ononis reclinata, Valantia hispida, Muscari spreitzenhoferi* και επίσης *Paronychia macrosepala, Plantago albicans, Filago aegaea, Piptatherum miliaceum*, οι οποίες στερούνται από άλλες ομάδες), καθώς και από έλλειψη αμμόφιλων ειδών. Οι σκληρόφυλλοι θάμνοι (*Juniperus, Periploca, Pistacia*), κυριαρχούν όσον αφορά την φυτοκάλυψη, ενώ οι χαμεφυτικοί θάμνοι είναι αρκετά ανεπτυγμένοι σε σύγκριση με τις άλλες φυτοκοινότητες. Η κοινότητα αυτή περιλαμβάνει επίσης ένα ικανό αριθμό ετησίων ποωδών ειδών, αλλά σε μικρότερο βαθμό από ότι οι άλλες κοινότητες. Οι πολυετείς πόες είναι λίγες, αλλά περιλαμβάνεται το απειλούμενο ενδημικό είδος *Colchicum coustourieri* και το αμμόφιλο *Pancratium maritimum*. Επίσης η συμμετοχή ξηρανθεκτικών ειδών είναι υψηλότερη από εκείνη των άλλων ομάδων. Όσον αφορά τα θρεπτικά συστατικά, κυριαρχούν είδη που αναπτύσονται σε φτωχές ή εξαιρετικά φτωχές περιοχές. Αναφορικά με την αλατότητα κυριαρχούν είδη τα οποία είναι μεσαίας ή μικρής ανθεκτικότητας στο αλάτι (halotolerant) ενώ είδη με υψηλή ανθεκτικότητα συμμετέχουν λιγότερο από ότι στις άλλες κοινότητες.

A2: *Malcolmia flexuosa-Nigella stricta*

Η φυτοκοινότητα αυτή βρέθηκε στο Κεδρόδασος σε αμμοθίνες μετρίου βάθους. Το χαρακτηριστικό είδος Malcolmia flexuosa μπορεί να σχετίζεται με την αυξημένη ύπαρξη βράχων. Ωστόσο, υπάρχει σημαντική συμμετοχή αμμόφιλων λιβαδικών ειδών *(Pseudorlaya pumila, Triplachne nitens* και *Vulpia fasciculata*). Οι σκληρόφυλλοι θάμνοι (*Juniperus, Pistacia, Ceratonia*) και οι χαμεφυτικοί θάμνοι είναι λιγότεροι και έχουν χαμηλότερη φυτοκάλυψη από ότι στις άλλες ομάδες και περιλαμβάνουν το ανθεκτικό στη βόσκηση ενδημικό είδος *Verbascum spinosum*. Κατά συνέπεια, οι πόες έχουν πολύ καλύτερη ανάπτυξη, κυριαρχούν τα μονοετή, αλλά υπάρχει σημαντική συμμετοχή του ανθεκτικού στη βόσκηση γεώφυτου *Urginea maritima*. Όσον αφορά την υγρασία, η χλωριδική σύνθεση είναι παρόμοια με τις άλλες ομάδες και κυριαρχούν είδη που αναπτύσονται σε ξηρές ή πολύ ξηρές θέσεις. Όσον αφορά τα θρεπτικά συστατικά, η συμμετοχή ειδών που αναπτύσονται σε μεσαίες ή πλούσιες θέσεις είναι αυξημένη. Το είδος *Chenopodium murale* είναι δείκτης πλούσιων σε θρεπτικά συστατικά περιοχών. Επίσης αυξημένη είναι η συμμετοχή ειδών που σχετίζονται με την παρουσία του ανθρώπου. (π.χ., *Urospermum picroides, Sonchus oleraceus, Mandragora autumnalis*), Αναφορικά με την αλατότητα κυριασχούν είδη μεσαίας ανθεκτικότητας στο αλάτι ενώ είναι αυξημένη η παρουσία αλόφοβων ειδών ή ειδών μικρής ανθεκτικότητας.

B1: *Silene colorata-Ononis natrix*

Είναι η κύρια κοινότητα σε μέτρια βαθειές αμμοθίνες στη Γαύδο υπάρχει επίσης στη νήσο Χρυσή και σε βαθειές αμμοθίνες στο Κεδρόδασος. Η χλωριδική σύνθεσή της χαρακτηρίζεται από τη σταθερή παρουσία ημίθαμνων και θάμνων, ενώ σε σταθεροποιημένες αμμοθίνες υπάρχουν λίγα αμμόφιλα είδη, ιδίως το *Limonium elaphonisicum*, και μια σειρά από ξηρανθεκτικά λιβαδικά είδη. Αντιπροσωπεύει συχνά τη μεταβατική ζώνη με πευκοδάσος ή θαμνώνες σε σταθερο υπόστρωμα και περιλαμβάνει θίνες με τραχεία πεύκη ή *Juniperus phoenicea*. Οι σκληρόφυλλοι θάμνοι (*Juniperus, Periploca, Pistacia, Ceratonia*), κυριαρχούν όσον αφορά την φυτοκάλυψη, ενώ οι χαμεφυτικοί θάμνοι είναι καλύτερα ανεπτυγμένοι σε σύγκριση με άλλες ομάδες. Η κοινότητα περιλαμβάνει επίσης ένα ικανό αριθμό μονοετών ποών με μικρή κάλυψη. Όσον αφορά την υγρασία, η χλωριδική σύνθεση είναι παρόμοια με των άλλων ομάδων, κυριαρχούν είδη που αναπτύσονται σε ξηρές ή πολύ ξηρές θέσεις ενώ υπάρχουν λίγα είδη που αναπτύσονται σε υγρές θέσεις. Όσον αφορά τα θρεπτικά συστατικά, κυριαρχούν είδη που αναπτύσονται σε φτωχές ή πολύ φτωχές περιοχές, σημαντική όμως είναι και η παρουσία ειδών που αναπτύσονται σε ενδιάμεσες ή πλούσιες σε θρεπτικά συστατικά περιοχές. Αναφορικά με την αλατότητα, τα είδη με μεσαία ανθεκτικότητα στο αλάτι είναι πολλά, παρουσιάζουν όμως μικρή φυτοκάλυψη όπως και τα είδη με μεγάλη ανθεκτικότητα στο αλάτι.

B2: ***Silene succulenta-Cutandia maritima***

Αυτή είναι η κύρια κοινότητα σε βαθειές αμμοθίνες σε όλες τις περιοχές. Παρατηρήθηκε κυρίως στη Γαύδο είναι συχνή στη νήσο Χρυσή αλλά σπάνια στο Κεδρόδασος. Η χλωριδική σύνθεση χαρακτηρίζεται λιγότερους θάμνους, με μεγάλη συχνότητα ειδών χαρακτηριστικών των σταθεροποιημένων αμμοθινών καί έλλειψη ξηρανθεκτικών λιβαδικών ειδών. Οι σκληρόφυλλοι θάμνοι (*Juniperus, Periploca, Pistacia*), κυριαρχούν οσον αφορά την φυτοκάλυψη, ενώ οι χαμεφυτικοί θάμνοι είναι λιγότερο ανεπτυγμένοι σε σύγκριση με τις κοινότητες B1 και A1. Στις πόες κυριαρχούν τα μονοετή είδη, αλλά η πολυετής πόα *Silene succulenta* έχει σημαντική φυτοκάλυψη. Όσον αφορά την υγρασία, η χλωριδική σύνθεση είναι παρόμοια με των άλλων ομάδων, κυριαρχούν είδη που αναπτύσονται σε ξηρές ή πολύ ξηρές θέσεις ενώ υπάρχουν λίγα είδη που αναπτύσονται σε υγρές θέσεις. Όσον αφορά τα θρεπτικά συστατικά, κυριαρχούν είδη που αναπτύσονται σε φτωχές ή πολύ φτωχές περιοχές, σημαντική όμως είναι και η παρουσία ειδών που αναπτύσονται σε ενδιάμεσες ή πλούσιες σε θρεπτικά συστατικά περιοχές. Αυτά είναι τα αμμονιτρόφιλα είδη *Cakile maritima* και *Salsola kali*, αμμόφιλα είδη καθώς και είδη που σχετίζονται με την παρουσία του ανθρώπου. Αναφορικά με την αλατότητα, κυριαρχούν είδη με υψηλή ανθεκτικότητα στο αλάτι, σημαντική όμως είναι η παρουσία αλόφιλων ειδών και ειδών ανθεκτικών σε πολύ υψηλή αλατότητα.

B3: *Elytrigia juncea-Medicago marina*

Η κοινότητα αυτή παρουσιάζεται σε εμπρόσθιες θίνες και βρέθηκε στην Χρυσή σε βαθειές αμμοθίνες και στα Φαλάσαρνα σε υποβαθμισμένες, μεσαίου βάθους ή επίπεδες αμμοθίνες. Η χλωριδική σύνθεση χαρακτηρίζεται από τη συμμετοχή αμμόφιλων ειδών χαρακτηριστικών των πρωτογενών αμμοθινών συμπεριλαμβανομένου του είδους *Centaurea pumilio* το οποίο χαρακτηρίζεται ώς ευάλωτο και καταγράφηκε στα Φαλάσαρνα. Οι σκληρόφυλλοι θάμνοι (*Juniperus, Pistacia, Lycium*), κυριαρχούν όσον αφορά την φυτοκάλυψη. Τα χαμέφυτα είναι λιγότερο ανεπτυγμένα σε σύγκριση με όλες τις άλλες κοινότητες, με εξαίρεση Α2, αλλά περιλαμβάνονται, το έρπον είδος *Medicago marina* και το είδος *Euphorbia paralias* χαρακτηριστικό είδος των πρωτογενών αμμοθινών. Στις πόες κυριαρχούν τα μονοετή είδη, αλλά σημαντική συμμετοχή έχουν και πολυετή ριζοματώδη γεώφυτα *Elytrigia juncea* και τα είδη πρωτογενών θινών *Eryngium maritimum* και *Sporobolus pungens*. Όσον αφορά την υγρασία, η χλωριδική σύνθεση είναι παρόμοια με των άλλων ομάδων, κυριαρχούν είδη που αναπτύσονται σε ξηρές ή πολύ ξηρές θέσεις ενώ υπάρχουν αρκετά είδη που αναπτύσονται σε υγρές θέσεις (*Sporobolus pungens, Pancratium maritimum* και *Cakile maritima*). Όσον αφορά τα θρεπτικά συστατικά, αυξημένη είναι η συμμετοχή ειδών που αναπτύσονται σε ενδιάμεσες ή πλούσιες θέσεις.. Αναφορικά με την αλατότητα, κυριαρχούν είδη πολύ ανθεκτικά στην αλατότητα ενώ σημαντική είναι η συμμετοχή ειδών μέσου ή μεγάλου εύρους αλατότητας.

Από την ανάλυση των δεδομένων των τομών βλάστησης προέκυψαν 18 φυτοκοινότητες οι οποίες αντιπροσωπεύουν την χωρική διαδοχή από την ακτή προς το εσωτερικό. Οι επιφάνειες δειγματοληψίας ομαδοποιούνται σε 4 κύριες ομάδες:

C - *Anthyllis hermaniae-Centaurea pumilio* (Κεδρόδασος);

D - *Silene succulenta-Pancratium maritimum* (πρωτογενείς και εμπρόσθιες θίνες κυρίως στη Χρυσή); *Silene succulenta-Pseudorlaya pumila* (πρωτογενείς θίνες και θαμνώδεις θίνες),

E - *Juniperus macrocarpa*

F - *Ononis natrix-Coridothymus capitatus* (κυρίως στη Γαύδο).

Τα είδη *Silene succulenta*, *Triplachne nitens* and *Lotus halophilous* παρουσίασαν την μεγαλήτερη συχνότητα σε όλες τις κοινότητες και σε όλες τις περιοχές εκτός του Κεδρόδασους.

Από την ανάλυση των δεδομένων των μόνιμων δειγματοληπτικών επιφανειών και των τομών βλάστησης αναγνωρίσθηκαν 36 θεμελιώδη είδη (32 του οικοτόπου 2250*) και 80 είδη δείκτες τα οποία μπορούν να χρησιμοποιηθούν στην εκτίμηση της ποιότητας του οικοτόπου 2250*.

Η χωρική διαδοχή της βλάστησης σύμφωνα με την ανάλυση των στοιχείων των τομών βλάστησης και των μόνιμων δειγματοληπτικων επιφανειών έχει ώς εξής:

Στις βόρειες ακτές της Χρυσής υπάρχει μια μεγάλη ζώνη πρωτογενών θινών (υψηλή κάλυψη στην δυτική πλευρά και χαμηλή κάλυψη, εκτός από μια γραμμή στο ανατολικό μέρος) με τυπική αμμόφιλη βλάστηση συμπεριλαμβανομένων και των ειδών που συγκρατούν την άμμο, πίσω από την οποία σχηματίζονται: υψηλότερες, εμπρόσθιες και στη συνέχεια εσωτερικές αμμοθίνες. Στο Κεδρόδασος η ζώνη των πρωτογενών αμμοθινών περιορίζεται σε μια στενή λωρίδα με χαμηλή φυτοκάλυψη όπου απουσιάζουν είδη που συγκρατούν την άμμο και στη συνέχεια εμφανίζονται απότομα υψηλότερες θίνες με χαμηλούς θάμνους ή Κέδρα. Στη Γαύδο, η τυπική διαδοχή των πρωτογενών-εμπρόσθιων-εσωτερικών θινών υπάρχει μόνο στο Σαρακήνικο, όπου η ζώνη των πρωτογενών θινών είναι εκτεταμένη αλλά υποβαθμισμένη και τα είδη *Medicago marina* και *Limonium elaphonesicum* είναι οι κύριοι σταθεροποιητές της άμμου. Στον Άγιο Ιωάννη και Λαυρακά οι πρώτες ζώνες συμπεριλαμβάνουν πρωτογενείς θίνες με χαμηλή βλάστηση ενώ στις βραχώδεις θέσεις οι εμπρόσθιες θίνες με Κέδρα εμφανίζονται απότομα.

1. Introduction

Coastal dunes are found on shores all over the world, from polar latitudes to the tropics (Martinez et al., 2004). Plant growth forms, sea and wind are the key factors that create, mold or destroy these deposits. Among these factors, plant growth plays a vital role in all stages of coastal dune formation by reducing the effect of the wind, trapping sand and so encouraging further dune growth (Musila et al., 2001). Time is also an important factor in this process, especially on prograding shorelines. A profile of these sandy deposits represents a time series, from young beach sands to older, often stabilized, inland deposits.

Coastal areas have a long history of human habitation. Human influence on coastal dune systems in the Mediterranean basin dates back several thousand years. The 20th century witnessed an intensification of human activity and the Mediterranean coast has deteriorated due to anthropogenic activities, such as excessive sand extraction from coastal dunes, beaches, and river mouths; human settlements and agriculture. Agricultural use of sand dunes is mainly for grazing, hunting, and cropping. Grazing with sheep, goats, or even cattle is even more widespread than cropping.

Since the 1970s, man has come to regard the seashore as a prime vacation spot. Large parts of the Mediterranean coastal dunes are used for tourist and domestic urbanization and for industrial development. Along the Spanish and French Mediterranean coast 75–80% of the sand dunes have been destroyed by tourism, urbanization, and industry. Comparable figures are also true for major parts of the Turkish coastlines. Sand dunes in Portugal, Greece, Israel, and Tunisia are under growing urbanization pressure as well.

Serious erosion as a result of mass recreation is reported for all European countries (van der Meulen and Salman, 1996). The coast of Crete is no exception, and represents a perfect example of the development pressure from which coastal landscapes and especially sand dune systems are vulnerable (Tzatzanis et al., 2003).

Mediterranean coastal dunes are characterized by a strong seasonality, with warm and wet winters and hot and dry summers (Castillo et al., 2002). Vegetation is exposed to high stress caused by drought, large evaporative demand, and high irradiance at high temperatures (Barbour et al., 1985, Figuerora et al., 1997, Fernandez-Baco et al., 1998, Lloret et al., 1999, Garcia Novo et al., 2004).

Mediterranean coastal dunes varying in height from 20 cm to 15 m can be found on many places along the Greek coast. Dunes are either treated as an extension of sand beaches, with beach-like forms of recreation, or seen as easily accessible areas for enjoying natural landscape.

Coastal dunes with *Juniperus* spp. (juniper) are widespread on the coasts of Europe, but not very common. This habitat (2250*) is distributed along the sandy coasts of Southern and Western Europe, on Mediterranean and Atlantic coasts. Italy hosts the main area of this habitat at EU level followed by Spain, France and Greece. This habitat is rare in the United Kingdom, where it is present only in Scotland (Figure 1). The distribution is very discontinuous, with large portions of habitat surviving mainly in protected areas.

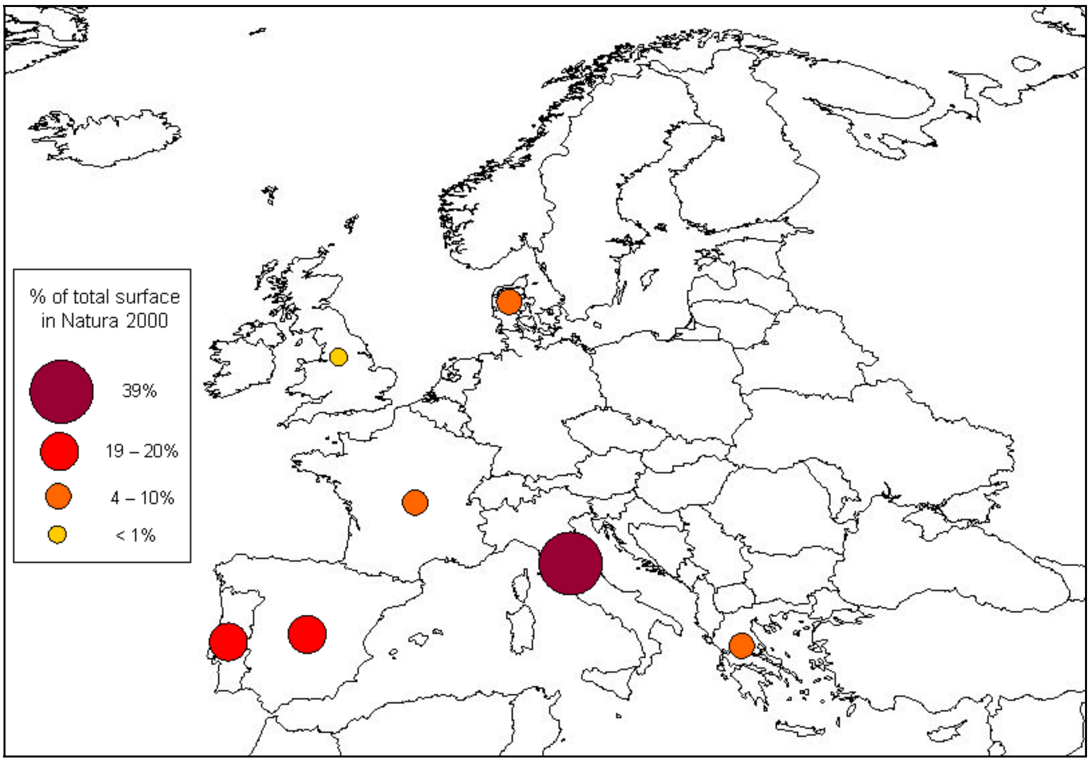


Figure 1 Percentage distribution of the total surface of costal dunes with *Juniperus* spp. in Natura 2000 sites across Europe (source: Picchi 2008).

The maritime juniper *Juniperus oxycedrus L*. ssp. *macrocarpa* (Sibth. & Sm.) Ball 1878 is a Mediterranean coniferous species (Post 1933; Maire 1952; Tutin et al. 1964; Jalas & Souminen 1973) which woodlands represent the late successional stage of the Mediterranean dunes and cliffs. According to Rivas-Martinez et al., 1980, the maritime juniper woodlands of *Juniperus oxycedrus* spp. *macrocarpa* with Phoenicean juniper *Juniperus phoenicea*, represents the mature ecosystem on outer dunes and cliffs of the Mediterranean coasts. Other species normally found in these woodlands in Crete include: *Anthyllis hermanniae*, *Silene succulenta*, *Coridothymus capitatus*, *Satureja thymbra*, *Ceratonia siliqua* (Carob tree), *Pistacia lentiscus* (mastic tree).

Juniper woodlands have a high ecological value in relation to their sand retaining ability, and associated habitat for flora and fauna. They constitute a singular vegetation type in an environment that has been traditionally seen as a place for socioeconomic development. Traditionally, juniper wood was used in construction and in the production of distilled oil for veterinary medicine.

Costal dunes with *Juniperus* spp. are vulnerable ecosystems due to its extreme ecological position (Gehu, 1993), withstanding the effects of wind, drought, salt, erosion and pH (Crawford, 1989; Brown and McLachlan, 1990). The severe influence of environmental factors such as high concentration of salt in the soil, salt spray and strong winds has created particular types of vegetation. Seeds of few species germinate and grow successfully under such adverse environmental conditions, and thus, plant cover and species diversity tend to be low in such coastal habitats (Goldstein et al., 1996) when compared with neighboring garrigues and phrygana. Nevertheless, the present plant communities are challenging, due to their lack of characteristic species as well as the resulting difficulties in phytosociological classification (Mayer 1995). The presence of endemic species forms a further aspect of interesting vegetation.

Costal dunes with *Juniperus* spp. are threatened by logging, urban development, tourism, forest fires, alien species, restricted natural regeneration of *Juniperus*, coastal erosion, grazing and browsing, habitat fragmentation, polluted sea spray and nutrient deposition. Moreover, Global climate changes may affect coastal juniper dunes through changes in minimum winter temperatures, modifying the distribution of several plant species and frequent storms, with the resulting damage to the seaward side of the dune slacks. Changes in dune structure and ecosystems are often cyclical, with periods of loss (erosion) balanced by periods of gain (sand deposition) so these tendencies will be obvious only in the long term (Corre 1991). Changes in storm frequency and intensity and the expected increase in sea level attributed to climate change could increase dune erosion due to more extensive coastal inundation and higher storm-surge flooding (EEA 2006). Warmer and sunnier weather will probably lead to an increase in domestic tourism (Viner & Agnew 1999). If the issue of higher visitor numbers to sea dunes is not properly addressed in advance, increasing pressure might have an adverse affect on them. An increase in temperature would probably affect species composition, but there are not enough studies on this subject. Also, the predicted higher rates of evaporation would have negative effects on juniper vegetation. Young juniper seedlings are vulnerable to summer drought and this climatic factor might have implications for juniper as regards any future global warming (Ward 2004). However, defining future climate threats on habitats and species is very unreliable due to the uncertainty associated with: future greenhouse gas emissions, the consequent changes in climatic features (e.g. temperature, precipitation CO2 concentrations), habitat and species responses to these changes (for instance, location, phenology, community structure) and the role of other socio-economic drivers of environmental change (JNCC 2007b).

Nowadays, the junipers appear in isolated stands of different extension. Large populations still survive in natural or semi-natural situations. Its habitats have been included in the European Union Habitats Directive as an acknowledgement of its threatened status in Europe (Anon. 1992). The protection of coastal woodlands is a priority because of the high natural values, recreation and sand stabilization. In addition to the high landscape values, coastal juniper woodlands are important because they harbor several endangered plant species.

Maritime juniper has been considered resistant to salt and sand-laden marine winds (Géhu et al. 1990), related to a stabilized stage of the dunes (Allier 1975), and linked to competition displacement or substrate requirements (García Novo & Merino 1993). A study by Munoz-Reinoso, 2004 on the diversity of maritime juniper woodlands along the southwestern coast of Spain, including juniper communities on sand dunes, cliffs, and as understory of pine plantations showed that cliffs have significantly higher richness and diversity values than dunes and pine plantations, while those in dunes and pine plantations were the same. Juniper woodlands on dune systems have a lower diversity of woody species due to the harsher environmental factors such as salt spray and sand mobility. On the cliffs, the environmental stress promoted by the salt spray is reduced by the elevation of the coast, and plant species composition is mainly controlled by lithology and climate. Juniper communities on cliffs had higher diversity values.

Studies of the relationship between vegetation and dune formation are few. Barker et al. (1989) investigated vegetation dynamics in coastal Somalia and concluded that sand dune encroachment directly influences vegetation structure and composition due to saltation and deposition. In South Africa's south coast more recent accounts have centered on the use of both indigenous and alien vegetation in dune stabilization and coastal management (Stehle 1988; Avis 1989). Castillo et al. (1991) studied the sand dune vegetation along the tropical coast of the Mexican states of Tabasco and Campeche. These studies show that coastal dunes form a complex system of habitats for plants due to the combined effect of steep environmental gradients which are related to the distance from the shoreline and to elevation. Important gradients are based on salinity, nutrients, humidity (due to spatio-temporal variations in the phreatic level), wind, and inundation (Ranwell 1972). Plants that are suited to the dune habitat are highly specialized; the ecosystem is characterized by water limitations for plant growth and also limited soil fertility. In fact, the main problem with dune stabilization using plants in many dunes exists in part, because the terrain is too dry to support vegetation. Even in a tropical humid climate such as that pertaining in coastal Kenya dry conditions are experienced due to high evaporations rates that are almost double the annual precipitation (Anon. 1996). Aside from any water limitations, juveniles may find it difficult to establish in shifting dune sands because their tiny roots may not be able to hold. Coastal dune vegetation also has to contend with the salt spray and nutrient limitation in dune soils. In this prograding shoreline, a temporal and spatial dune succession is found. The ecological aspects of dune succession have been discussed by Willis et al. (1959), Ranwell (1972) and van der Maarel et al. (1985) albeit for climatic conditions different from Kenya. Work by Melton (1940), Cooper (1958), Ash & Wasson (1983), Sarre (1989), Carter & Wilson (1990), Thomas & Tsoar (1990) and Wolfe & Nickling (1993) has clearly demonstrated that vegetation has an important control on dune morphology as it impedes sand movement in several ways: 1. Aerial roots and plant form increase the effective roughness of the sand surface. 2. Roots also have a direct binding effect on the surface sand layers. 3. Humus derived from dead vegetation increases the cohesive and water retentive properties of the surface sand. 4. Vegetation extracts momentum from the air flow. 5. Vegetation elements present an obstacle for incoming saltation. 6. The part of the surface that is covered by vegetation is withdrawn from the sediment supply system (Wolfe & Nickling, 1993).

In the late 20th century, conservation efforts were focused on plant inventories, preserving rare species from extinction and maintaining the habitats of as many species as possible. Today, attention is more sharply focused on understanding the physical and ecological processes that take place in these habitats. Sustainable use of coastal areas will depend largely on involving local communities and governments in the decision-making process so as to effectively manage these areas to the satisfaction of all users.

Vegetation is by far the most important component of the biota on sand dunes because it is directly involved in establishing the dune forms and creating the structure of the dune habitat (Wolfe and Nickling, 1993). In spite of their ecological value, maritime juniper woodlands are poorly known. In addition, there is a lack of information about their ecology as a basis for future restoration plans. Moreover, there is no available data describing the composition, the structure and the ecological processes of this priority habitat in Greece. Therefore, it was considered interesting from an ecological point of view and urgent from a conservation and land use perspective to systematically describe and classify the plant communities, using collected data over all the Cretan dune systems included in the Natura 2000 network. This report focuses on the Coastal juniper woodlands vegetation, which is an important indicator of the general physical conditions of the coastal dune with *Juniperus* spp. environment.

The objective of this report was to conduct surveys to determine and describe the composition, the structure, and the ecological processes of juniper woodland communities on all Cretan sites.

2. Study areas

Surveys were carried out in all Natura 2000 designated coastal dunes with *Juniperus* spp. (2250*) habitats of Crete located in Chrysi, Gavdos, Kedrodasos-Elafonisi and Falasarna.

2.1 Kedrodasos

Kedrodasos-Elafonisi is located in the south western corner of Crete (35°16’09,15’’ N and 23°33’31,56’’ E), 1.5 km east of the Elafonisos area. Administratively it belongs to the municipality of Pelekanou/prefecture of Chania (Figure 2). The climate is typical Mediterranean, with moderate rainfall and long, dry hot summers with relatively high winter temperatures. Mean annual temperature is 19.63^{o}C, with monthly means attaining 27.7^{o}C in July and August and 12.2^{o}C in February. Annual rainfall is 477.2 mm, of which 90% occurs during the winter period (data for the year 2005 from Koudoura meteorological station). The Juniper forest (Kedrodasos) is growing on a rocky substrate covered by thick sand. The vegetation in Kedrodasos is mainly dominated by coniferous scrub and woodland (*Juniperus oxycedrus* spp. *macrocarpa*, *Juniperus phoenicea*), by lentisk formations and other keystone species such as *Ceratonia siliqua* and *Coridothymus capitatus*. The main present use of the habitat consists of recreation with an unknown number of visitors using the site for swimming and camping. Following the implementation of European Habitats directive, the area of Elafonisos has been designated a Natura 2000 site (code GR4340015, name: Paralia Apo Chrysoskalitissa Mechri Akrotirio Krios). The priority habitat of Coastal dunes with *Juniperus* spp. (Kedrodasos) within the Natura 2000 site of Elafonisos exists in one location and covers an area of 11.3 ha in total (Figure 2).

2.2 Chrysi

Chrysi is located southeast of Crete (34°51’40’’ N and 25°42’50’’ E), 15 km south of the municipality of Ierapetra, Prefecture of Lasithi (Figure 2). Chrysi has an area of approximately 5 km^2, a maximum altitude of 31 m and geologically consists of cherts, sandstones and breccia. The climate is typical Mediterranean, with moderate rainfall and long, dry hot summers with relatively high winter temperatures. Rainfall is limited to an annual average of 550 mm (period 1938-1975) that falls mostly from October to March (Pennas, 1977). Rackham and Moody 1996 report more recent and drier periods and estimate less than 450 mm of rainfall. The vascular flora comprises 275 taxa. The north African/south Mediterranean/west Irano-Turanian is the phytogeograhically most striking (Bergmeier et al., 2001). The vegetation in Chrysi is mainly dominated by coniferous scrub and woodland (*Juniperus oxycedrus* spp. *macrocarpa*, *Juniperus phoenicea* and *Pinus halepensis* subsp. *brutia*). In the East part of Chrysi one of the few salt marshes in the South Aegean exists, with the halophytes *Arthrocnemum macrostachyum* and *Aeluropus lagopoides* predominating. A single small stand of *Schoenoplectus litoralis* occurs not far from the NW shore. Steppe-like *Lygeum* grasslands are indicative vegetation for the driest region in Europe. Although practiced for centuries, grazing by sheep and goats has been ceased due to the absence of sweet water (Bergmeier et al., 2001). Following the implementation of European Habitats directive, Chrysi has been designated a Natura 2000 site (code GR4320003, name: Nisos Chrysi). Coastal dunes with *Juniperus* spp. on the island of Chrysi exists in two locations and covers an area of 70 Ha in total (Figure 2).

2.3 Gavdos

Gavdos lies 28 miles off the island of Crete and 150 miles off the shores of northern Africa (34°52'36'' N and 24°05'25'' E) (Figure 2). It has an area of 30 km^2, a maximum altitude of 362 m and geologically consists of upper Cretaceous limestones. The climate is typical Mediterranean, with moderate rainfall and long, dry hot summers with relatively high winter temperatures. Rainfall is limited to an annual average of c.400 mm that falls on about 90 days a year, mostly from October to March (Bergmeier, 2001). The vascular flora comprises c.460 taxa, 30 of which (6%) are of south Mediterranean/north African origin, which on the island are at their European northern distributional limit (Bergmeier et al., 1997). The vegetation in Gavdos is mainly dominated by pine, juniper and lentisk formations, in a unique cultural landscape of terraces, where wheat and barley are still grown (Rackham & Moody, 1996). Following the implementation of European Habitats directive, Gavdos has been designated a Natura 2000 site (code GR4340013, name: Nisoi Gavdos kai Gavdopoula). Coastal dunes with *Juniperus* spp. on the island of Gavdos exists in three locations (Agios Ioannis, Lavrakas, and Sarakiniko) on the northern coasts and covers an area of 102 Ha in total (Figure 2). Although small and sparsely populated, Gavdos is administratively independent with its own community, and belongs to the prefecture of Chania. Based on National Census 2001, Gavdos has a population of 80 residents 50 of which live permanently on the island, consisting of 24 households (Oikos, 2008). It should be noted that each priority habitat has its particularities and threats. Both Agios Ioannis and Lavrakas are not accessible by car, can be considered remote, and used for tourism (camping) and grazing. Sarakiniko on the other hand, is accessible by road, and is located next to a popular beach and area undergoing tourism development, as well as, being used for grazing.

2.4 Falasarna

Falasarana is located in western Crete on the neck of Cape Grambousa (Figure 2), or Korykos as it was called in antiquity. Administratively it belongs to the municipality of Kissamos/Chania Prefecture. The climate is typical Mediterranean, with moderate rainfall and long, dry hot summers with relatively high winter temperatures. Following the implementation of European Habitats directive, the area of Falasarna has been designated a Natura 2000 site (code: GR4340001, name: Imeri kai Agria Gramvousa - Tigani kai Falasarna - Pontikonisi, Ormos Livadia-viglia) since it hosts a significant number of priority habitats s such as Costal dunes with *Juniperus* spp, Mediterranean Temporary Ponds and other priority and endangered species such as *Androcymbium rechingeri*. The geology of the area comprises mainly calcareous rocks (limestone) and neogene deposits in the lowland. The topographic slope is relatively low in the coastal and central zone and increases close to the eastern boundary of the catchment. The priority habitat of costal dunes with *Juniperus* spp. is located in the western part of the basin close to the coastline (Figure 2). The habitat is fragmented and traversed by a tarmac road cutting the habitat in two. The surrounding area of the habitat is characterized by intensive and expanding agricultural activities mainly greenhouses, as well as tourism.

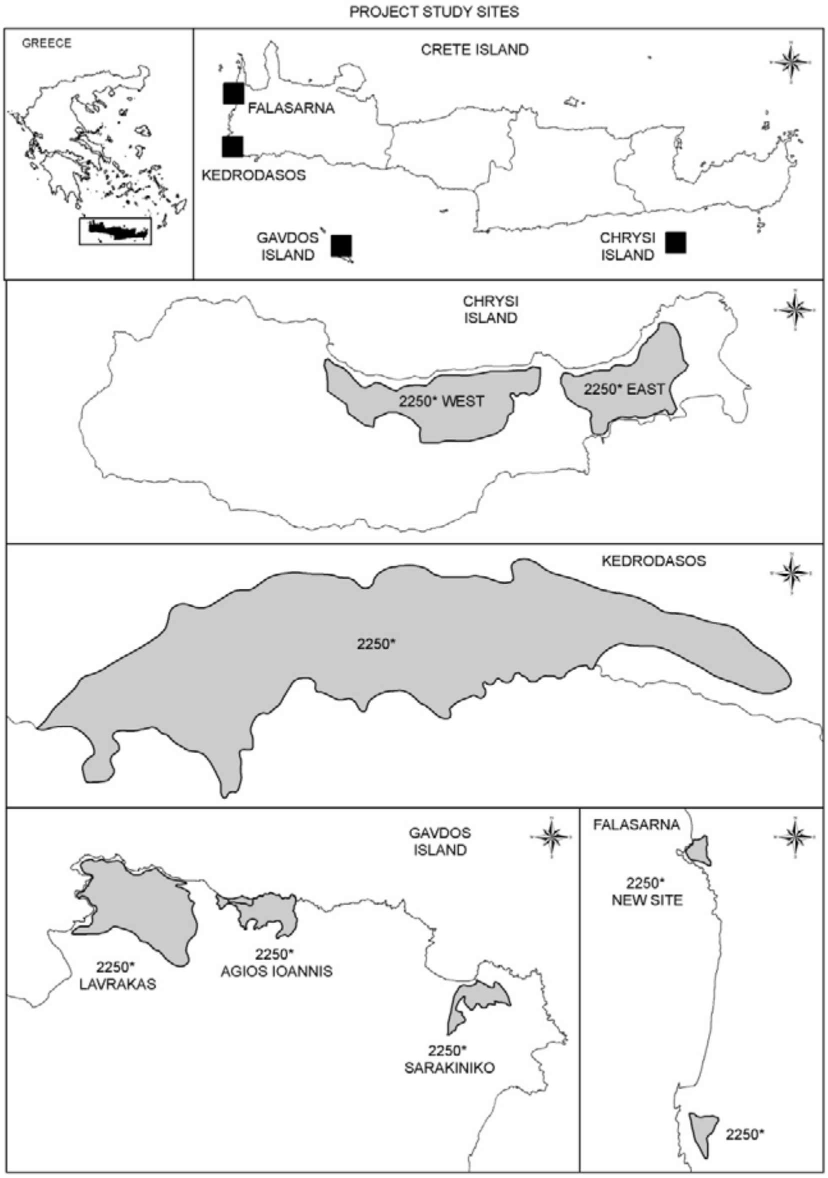


Figure 2 Location of the 2250* priority habitats in Chrysi, Kedrodasos-Elafonisi, Gavdos and Falasarna

3. Data collection

Fieldwork took place during May 2009 for the habitats in Kedrodasos and Gavdos (Sarakiniko, Agios Ioannis and Lavrakas), while for Chrysi and Falasarna fieldwork took place during April and May of 2010. At each site a number of 30x30 m vegetation plots (6 in Kedrodasos-Elafonisi, 4 in Sarakiniko-Gavdos, 6 in Agios Ioannis-Gavdos, 8 in Lavrakas-Gavdos, 10 in Chrysi and 2 in Falasarna) were established. All vegetation plots locations were geo-referenced using global positioning system. Each 30x30 m vegetation plot included two relevés: 10x10 m (see Appendix 1) and 3x3 m. The 10x10 m relevés included trees (Juniperus) whereas the 3x3 m relevés were established in open areas (did not include any tree). The percentage cover of trees, shrubs, phrygana and forbs were visually estimated in all 10x10 m and 3x3 m subplots. The height of woody vegetation was also estimated. Species composition of the vegetation was recorded and abundance was estimated using the Braun-Blanquet 9-grade cover-abundance scale as the following:

R: very rare, 1-2 individuals (average cover: 0.02%),

+: rare, few individuals (average cover: 0.1%),

1: many individuals <5% (average cover: 2.5%),

2m: cover 5% (average cover: 5%),

2a: cover 5-12% (average cover: 8.75%),

2b: cover 12-25% (average cover: 18.75%),

3: cover 25-50% (average cover: 37.5%),

4: cover 50-75% (average cover: 62.5%),

5: cover >75% (average cover: 87.5%)

Moreover, several line transects perpendicular to the seashore, passing through the embryo dunes (where present) were laid from the beach to the hinterland (2 line transects in Kedrodasos-Elafonisi, 1 in Sarakiniko-Gavdos, 3 in Agios Ioannis-Gavdos, 2 in Lavrakas-Gavdos, and 4 in Chrysi). All line transects were used as a baseline on which 5x5m contiguous sampling quadrats were located (see Appendix 1). Quadrats were demarcated and floristic data were measured every 5 m apart along each transect. The cover of each species was estimated using the same Braun-Blanquet 9-grade cover-abundance scale method. Transect length varied from 55 m to 225 m (Table 1) depending on dune morphology and on the length of the natural vegetation strips, which were often heavily modified by human impact. All vegetation transects locations were geo-referenced using global positioning system.

Plant species were identified in the field; those that could not be identified were taken to the herbarium of the Mediterranean Agronomic Institute of Chania. Plants' nomenclature follows Turland et al. (1993) and life-form spectrum classification follows Raunkiaer (1934). Chorology was based on Jahn & Schönfelder (1995). Environmental data such as the slope and aspect of each subplot were recorded. Voucher specimens were collected and stored in the Herbarium of the Mediterranean Agronomic Institute at Chania, Crete.

Table 1 Characteristics of the vegetations transects at all sites

	Site	**Length (m)**	**Distance from the sea (m)***	**Position of the 5x5 quadrats**
T1	Chrysi East	225	22	On the left
T2	Chrysi East	125	26	On the left
T1	Chrysi West	145	10	On the right
T2	Chrysi West	135	10	On the left
T1	Agios Ioannis-Gavdos	95	16	On the right
T2	Agios Ioannis-Gavdos	65	44	On the right
T3	Agios Ioannis-Gavdos	85	15	On the right
T1	Lavrakas-Gavdos	95	7	On the right
T2	Lavrakas-Gavdos	125	10	On the right
T1	Sarakiniko-Gavdos	115	12	On the right
T1	Kedrodasos	65	12	On the left
T2	Kedrodasos	55	5	On the left

*“Distance from the sea” correspond to the start point of each transects from which the vegetation presence starts to appear

4. Data analysis

The field data from the plots and transects were recorded in the TURBOVEG (© 1998-1999 Hennekens S.) database “juniper”.

We used the Shannon-Wiener (H' = −Σ Pi ln Pi) and Simpson (D = 1− Σ Pi2) indices to assess species diversity at the plot level. Pi is the abundance of each species at a plot (Krebs 1999). We carried out a comparison between the JUNICOAST vegetation survey and the one conducted in 1999 prior to the designation of the sites as Natura 2000 areas in order to get a picture of any changes in floristic composition. For this purpose the Sørensen similarity coefficient Ss was employed as a measure of floristic similarity between the two surveys (Kent and Coker 1992):

$$S_s = \frac{2a}{2a + b + c}$$

where a is the number of common species between two surveys, b is the number of species unique to the first of the two surveys and c is the number of species unique to the second survey. The same index was also used to examine floristic similarity between the four sites.

We used the Two-Way Indicator Species Analysis (TWINSPAN; Hill, 1979) within PC-ORD version 4 (McCune & Mefford, 1999) to classify vegetation data. Presence/absence data were analyzed and the classification was stopped at the third level of division, so that the resulting groups would contain a sufficient number of samples to characterize the vegetation communities. Since the 10x10 and 3x3 plots were collected from different environments and for different purposes they were also analyzed separately. The exploration of the major patterns of the species data and their relation to environmental variables was made by linear (Principal Component Analysis-PCA) or unimodal (Detrended Correspondence Analysis-DCA, Canonical Correspondence Analysis-CCA) ordination techniques, as appropriate in each case, with the software package CANOCO (ter Braak and Smilauer 1998[1]).

[1] ter Braak C.J.F. and Smilauer P. (1998). CANOCO 4, CANOCO Reference Manual and User’s Guide to Canoco for Windows. Centre for Biometry. Wageningen.

The sand dune flora in the project sites based on the vegetation and transect data is presented in Appendix 2, along with their life forms (Jahn & Schönfelder, 1995[2]), Ellenberg indices (Böhling et al., 2002[3]) and functional attributes (according to Espejel et al., 2004[4] plus the property of sand fixing). Data analysis included only the Ellenberg indices for moisture (F), nutrients (N), and salt (S) because they presented significant variation among the species, while the indices for light (L, values 6 to 9, semi-light to light plants), pH (R, values 7 to 9, weakly basic to basic soils), and temperature (T, values 7 to 8, fairly hot to hot sites) did not present significant variation.

[2] Jahn, R. & Schönfelder, P. (1995) *Exkursionsflora für Kreta*. Verlang Eugen Ulmer, Stuttgart (Hohenheim)
[3] Böhling N., Greuter W., Raus T. 2002. Zeigerwerte der Gefäßpflanzen der Südägäis (Griechenland). Braun-Blanquetia - Review of Geobotanical Monographs 32: 1-108
[4] Espejel I., Ahumada H., Cruz Y. and Heredia A. 2004. Coastal Vegetation as Indicators for Conservation. In: Ecological Studies, Vol.171, Martinez M.I. and Psuty N.P. (eds.). Coastal Dunes, Ecology and Conservation. Springer-Verlag Berlin Heidelberg, Germany, 297-318

5. Results

5.1 Species Composition

The total number of species recorded in the 4 sites was 142 belonging to 33 different families and 6 life forms. The number of species in each site is given in Table 2. In terms of absolute species richness Kedrodasos had the highest number of species and Falasarna the lowest (Table 2).

Table 2 Comparison between Natura 2000 and JUNICOAST sampling

Site	**Natura 2000 No of species**	**JUNICOAST No of species**	**Sørensen Index**
Kedrodasos	101	92	0.75
Gavdos	78	62	0.65
Chrysi	38	75	0.48
Falasarna	20	37	0.45

The dominant families were Poaceae (14%), Compositae (13.4%) and Fabaceae (11.3%). Therophytes are the dominant life form (56% of total species) followed by Chamaephytes (16%). Life form composition is quite similar in the four sites (Figure 3). In Kedrodasos therophytes are by far the dominant element of the site's flora (72%). Gavdos has the highest percentage of Chamaephytes (24%) and phanerophytes (8.7%). The dominant chorological element was the Mediterranean (26%) followed by the East-Mediterranean (12%), South-Mediterranean (10%) and Mediterranean-Atlantic (9.1%). The percentage of endemics accounted for 4.9% of the flora (7 out of 142 species) found in all study sites. Chrysi showed the highest number of endemics (4 species in total out of 7), followed by Gavdos and Kedrodasos-Elafonisi (3 species out of 7). The highest floristic similarity was between the two islands of Chrysi and Gavdos while the lowest between the two sites on Crete i.e. Falasarna and Kedrodasos (Table 3).

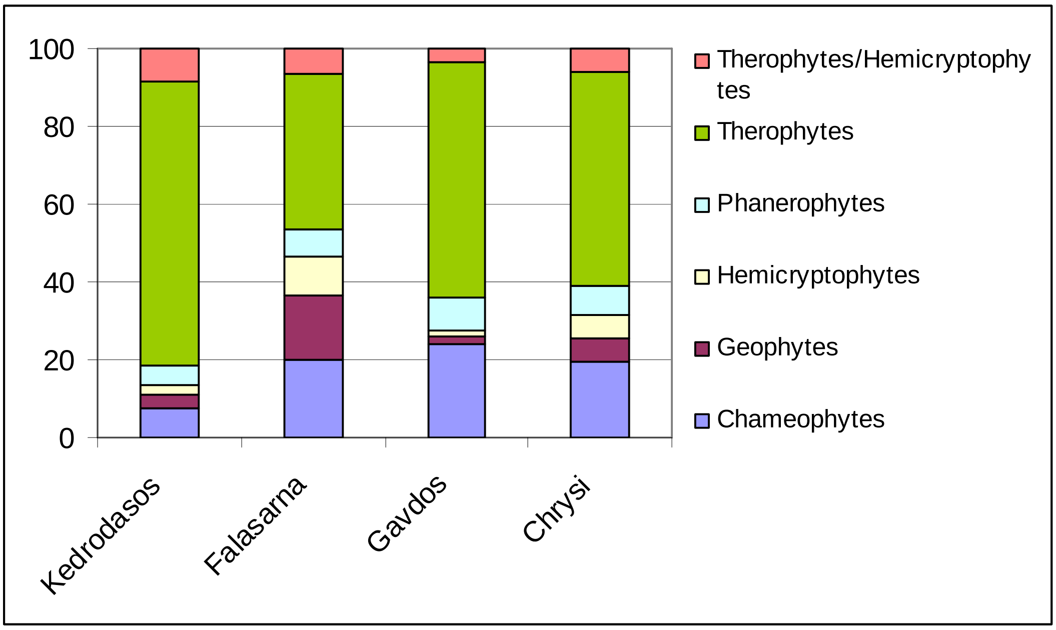


Figure 3 Percentage life form compositions in the study sites

When comparing the JUNICOAST vegetation survey and the pre-Natura 2000 survey the highest floristic similarity was in Gavdos (0.75) while the lowest was in Falasarna (0.45).

Table 3 Floristic similarity (Sørensen index) between sites

	Kedrodasos	Falasarna	Gavdos	Chrysi
Kedrodasos	1			
Falasarna	**0.14**	1		
Gavdos	0.43	0.25	1	
Chrysi	0.43	0.31	**0.48**	1

The results corroborate the floristic richness and ecological importance of the sand dunes vegetation in the four study sites. The sites investigated in this study are characteristic of the Mediterranean sand dune and include a range of communities from foredunes to mature dune vegetation. Most of the sites examined are relatively isolated. Two are located on two islands with limited seasonal access from the mainland and no roads while the other two found on Crete have access all year round which is facilitated by the presence of roads. Juniper trees occur at densities varying from completely isolated trees, to stands of open-grown trees. Stands of intermediate density occur as a mosaic of open and canopy-covered patches.

Among the tree elements pine is an exclusive element of the sand dunes in Gavdos, *Pistacia* is present in all sites examined while *Ceratonia* only in Gavdos and Kedrodasos.

When comparing the sites floristically there are higher bio-geographic affinities between the two islands off Crete i.e. Gavdos and Chrysi while the comparison between this survey and pre-Natura 2000 survey demonstrated a close match in species composition. Some discrepancies identified could be attributed to difference in sampling effort but also on seasonality/phenology. Despite these differences the majority of indicator species as well as endemics where present/common in both surveys.

5.2 Plot data analysis

5.2.1 Vegetation Classification

The vegetation groups identified by the analysis of the 10X10 plot data represent the various communities of *Juniperus macrocarpa* and/or *Juniperus phoenicea* (habitat type 2250*) occurring on sand dunes in Crete.

The species with the highest frequency in all the plots regardless of the various environmental parameters (geology, disturbances etc.) were three non-ammophilous species, the phryganic shrubs *Coridothymus capitatus* and *Phagnalon graecum* (26 and 21 plots, respectively) and a dry grassland small annual, *Hedypnois cretica* (22 plots); and the ammophilous annuals *Pseudorlaya pumila* (29 plots), *Triplachne nitens* (26 plots), *Vulpia fasciculata* (21 plots) and *Lotus halophilus* (24 plots). These species are candidates for keystone species for habitat 2250.

The results of the community analysis are shown in Figure 4. The life form spectra per vegetation group are presented in Figure 5 and the spectra for moisture, nutrients and salt are presented in Figure 6.

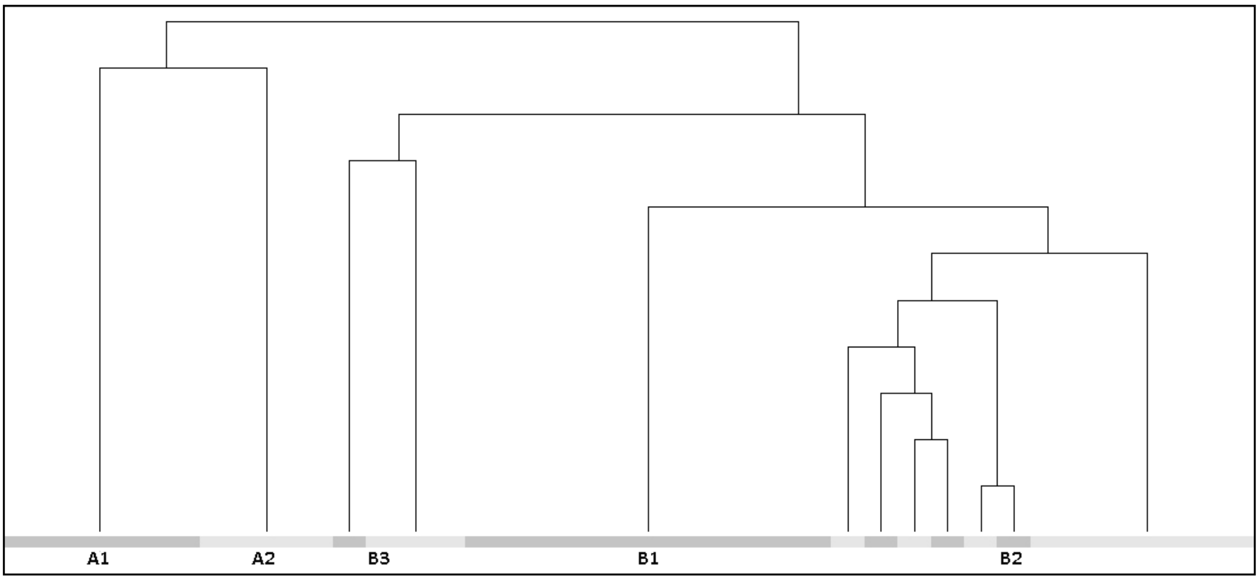
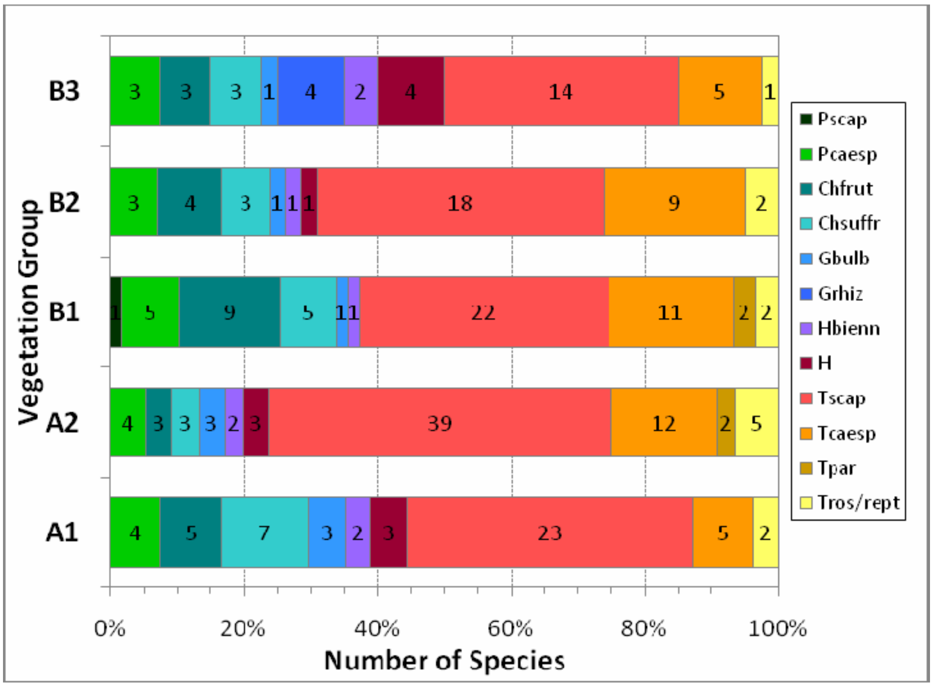


Figure 4 Hierarchical classification of the vegetation data (communities A1, A2, B1, B2, B3).



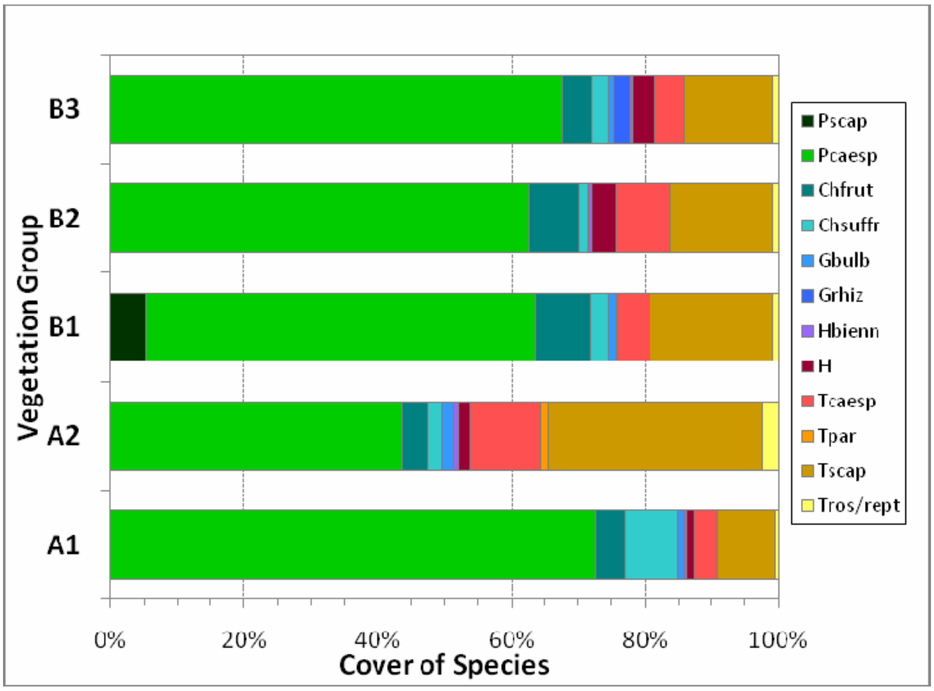


Figure 5 Life form spectra based on the number of plants (a) and on the percent cover of plants (b) in each vegetation group (A1, A2, B1, B2, and B3).

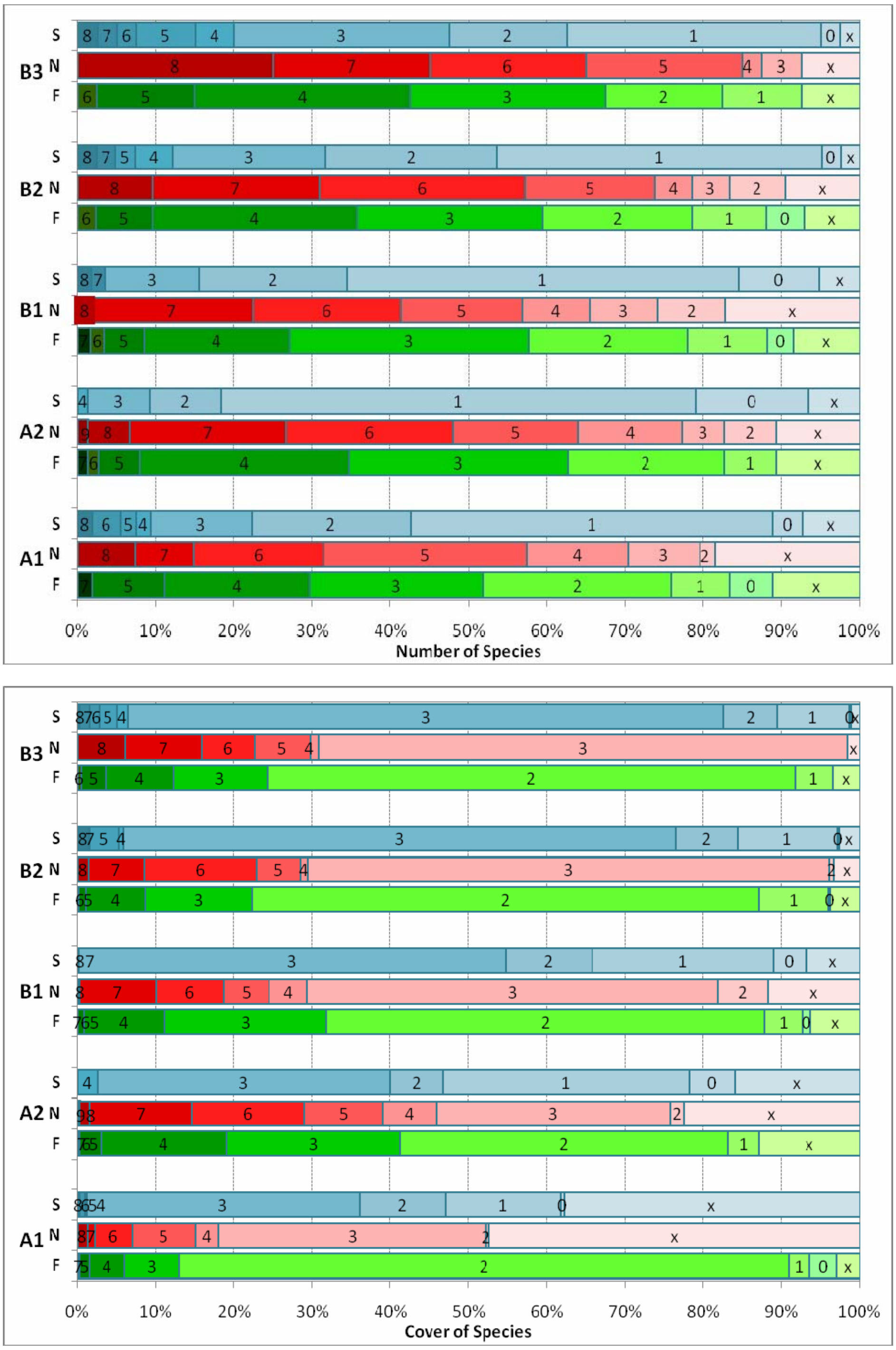


Figure 6 Spectra for moisture (F), nutrients (N), and salt (S) based on the number of plants (a) and on the percent cover of plants (b) in each community (A1, A2, B1, B2, B3).

The TWINSPAN analysis resulted in the following distinct groups, which are presented in a dendrogram (Figure 4):

- The first division separated the 38 plots into two groups on the basis of *Muscari spreitzehoferi, Valantia hispida, Phagnalon graecum and Arenaria leptoclados* for the negative group (14 plots) and *Silene colorata* for the positive group (24 plots).
- The second level of division separated the group of 14 into two groups of 7 plots each. This division was based on *Coridothymus capitatus, Lagurus ovatus* and *Plantago squarrosa.* On the left part of the same division, the 24 plots derived were split on the basis of *Pancratium maritimum*. The species was present in the positive group (20 plots) but not in the negative group (4 plots).
- The third level of division separated the group of 20 plots in the left side of the dendrogram into a new group of 7 plots, where *Phagnalon graecum* was the indicator species and 13 plots where *Silene succulenta* and *Prasium majus* was the indicator species. No further division was performed since the groups were too small.

The groups identified as ecologically meaningful are highlighted in Figure 4 and will be further discussed.

After classifying the vegetation data into groups, the characterization of these groups was based on the presence of mutually associated species in the sample plots according to TWINSPAN species classification. Species classification in TWINSPAN is based on fidelity, i.e. the degree to which species are confined to particular groups of plots. Fidelity ranges from 1 (accidental species in a group of plots) to 5 (exclusive species in a group of plots) (Kent & Coker 1992). Fidelity is dependent on the size of the area surveyed. Thus ideally it should be assessed only when the vegetation of an area has been described. Therefore constancy was also used to name the groups identified in this classification. The constancy value refers to the number of times each species is present in the plots that belong to a certain vegetation group.

Species with a constancy range between 50 - 75 % that occurred together in more than one plot, while at the same time having a high degree of fidelity were termed *characteristic* and were used to name each community. The vegetation units identified here are referred to as "community types" (cf. Mueller-Dombois and Ellenberg, 1974), since they have not been placed into existing phytosociological categories.

Community A1: *Juniperus phoenicea-Periploca angustifolia* community type (6 plots). This community represents shrubs with *Juniperus phoenicea* often mixed with *Juniperus macrocarpa*. It occurs on Chrysi Island, on shallow or moderately deep dunes with shallow or moderately deep interdunes, on marls. It occurs mainly on flat dunes and also at the transition zones to the shrublands of the inner island. Similar communities may occur on Gavdos Island but were not found in plots.

The floristic composition is characterized by the stable participation of phrygana and sclerophyllous shrub species (notably of *Helianthemum stipulatum*), by a high frequency of mostly annual dry grassland species (e.g., *Ononis reclinata*, *Valantia hispida*, *Muscari spreitzenhoferi* and also *Paronychia macrosepala*, *Plantago albicans*, *Filago aegaea*, *Piptatherum miliaceum*, which lack from other groups) and by a lack of ammophilous species.

The sclerophyllous shrubs (*Juniperus*, *Periploca*, *Pistacia*), which form the tall shrub layer (Pcaesp), are the dominant life form regarding cover while the layer of chamaephytic shrubs and especially of subshrubs (Chfrut, Chsuffr) is quite well developed compared to other groups. The community also includes a fair number of herbs with small cover, mostly annuals (Tscap, Tros, Trept, Tpar), but at a lesser degree than other groups. The perennial herbs are few, but include the threatened endemic bulb *Colchicum coustourieri* and the ammophilous *Pancratium maritimum*. Regarding moisture, the floristic composition is similar to other groups in the number of plants, with a dominance of plants of dry to extremely dry sites (values 3-0) and a few plants of fresh to damp sites. The presence of *Centaurium tenuiflorum*, an indicator of damp sites which may be springtime wet-summer dry may indicate the presence of minute temporary ponds among the shrubs, a situation occurring in other juniper shrubs in the Aegean). However, regarding cover the participation of plants of very to extremely dry sites (values 2 and smaller) is higher than that of the other groups. Regarding nutrients, the plants of poor to extremely poor sites are dominant and the plants of intermediate or nutrient rich site participate at a lesser degree than in all other groups. Regarding salt, the medium to slightly halotolerant plants and indifferent plants dominate, and the very halotolerant plants to euhaline plants participate at a lesser degree than all the other groups, except group A2.

Community A2: *Malcolmia flexuosa-Nigella stricta* community type (5 plots). This *Juniperus macrocarpa* community was found at Kedrodasos/Elaphonisi, on moderately deep dunes with moderately deep interdunes, on conglomerate. The characteristic species *Malcolmia flexuosa* may be related to the increased rock cover; however, there is a significant participation of ammophilous dune grassland species, mainly *Pseudorlaya pumila*, *Triplachne nitens* and *Vulpia fasciculata*. *Nigella stricta* is a rather rare Aegean endemic growing only in sand dune shrubs.

The layers of the tall sclerophyllous shrubs (*Juniperus*, *Pistacia*, *Ceratonia*) and the chamaephytic shrubs and subshrubs have lower cover and number than all the other groups and include the resistant to grazing endemic *Verbascum spinosum*. Consequently, the herb layer is much better developed and dominated by annuals but there is significant participation of the resistant to grazing geophyte *Urginea maritima*. Regarding moisture, the floristic composition is similar to other groups, with a dominance of plants of dry to extremely dry sites (values 3-0), but there is less participation of plants of very and extremely dry sites. Regarding nutrients, the participation of plants of intermediate and rich sites (values 5 to 8) is significantly increased and there is even an indicator of extremely nutrient rich sites, *Chenopodium murale* (value 9). The increased nutrient indicator values are mainly due to the increased participation of synanthropic vegetation species (e.g., *Urospermum picroides*, *Sonchus oleraceus*, *Mandragora autumnalis*), rather than to the participation of nitrophilous sand dune plants. Regarding salt, the medium to slightly halotolerant plants and indifferent plants dominate; the participation of slightly halotolerant and halophobe plants is increased compared to other groups and there are no euhaline plants.

Community B1: *Silene colorata-Ononis natrix* community type (12 plots). This is the main *Juniperus macrocarpa* community of moderately deep dunes on Gavdos and also occurs on Chrysi and at the deep dunes of Kedrodasos. Its floristic composition is characterized by the stable presence of subshrubs and shrubs, by few ammophilous species of stabilized (or semi-stabilized) dunes, notably of *Limonium elaphonisicum*, and an array of dry grassland species. It often represents the transition zone to pine forest or shrub on stable substrate and includes dunes with *Pinus brutia* or *Juniperus phoenicea*.

The sclerophyllous shrubs (*Juniperus*, *Periploca*, *Pistacia*, *Ceratonia*), which form the tall shrub layer (Pcaesp), are the dominant life form regarding cover while the layer of chamaephytic shrubs (Chfrut) is better developed compared to other groups. The community also includes a fair number of herbs with small cover, mostly annuals, but of less cover than other groups, except from group A1. Regarding moisture, the floristic composition is similar to other groups, with a dominance of plants of dry to extremely dry sites (values 3-0) and a few plants of fresh to damp sites. The presence of *Lotus angustissimus*, an indicator of damp sites which may be springtime wet-summer dry may indicate the presence of minute temporary ponds among the shrubs. Regarding nutrients, the plants of poor to extremely poor sites are dominant, but the plants of intermediate or nutrient rich sites have a significant participation, too. These are both ammophilous species, such as *Vulpia fasciculata* and *Medicago littoralis* and synanthropic vegetation species, such as *Sonchus oleraceus* and *Euphorbia peplus*. Regarding salt, the medium to slightly halotolerant plants have a larger number but equal cover to the very halotolerant to euhaline plants (the latter have a very small cover).

Community B2: *Silene succulenta-Cutandia maritima* community type (9 plots). This is the main *Juniperus macrocarpa* community of deep dunes at all sites. It was observed mainly on Gavdos and it is also frequent on Chrysi but rare at Kedrodasos. The floristic composition is characterized by a less prominent shrub layer, by high frequency of stabilized (or semi-stabilized) dune species and a lack of other dry grassland species.

The sclerophyllous shrubs (*Juniperus*, *Periploca*, *Pistacia*), which form the tall shrub layer (Pcaesp), are the dominant life form regarding cover while the layer of chamaephytic shrubs and subshrubs is less developed compared to communities B1 and A1. The herb layer is dominated by annuals, but one perennial hemicryptophyte (H), *Silene succulenta* has a significant cover. Regarding moisture, the floristic composition is similar to other groups, with a dominance of plants of dry to extremely dry sites but with fewer plants of fresh to damp sites. Regarding nutrients, the plants of poor to extremely poor sites are dominant, but the plants of intermediate or nutrient rich sites have a significant participation, too. These are ammonitrophilous drift line species, such as *Cakile maritima* and *Salsola kali*, and ammophilous species and synanthropic vegetation species. Regarding salt, the very halotolerant plants are dominant and there is a significant participation of meso- to euhaline plants.

Community B3: *Elytrigia juncea-Medicago marina* community type (4 plots). This community occurs on foredunes and was found on Chrysi, on deep dunes and at Falasarna on degraded, medium deep or flat dunes. The floristic composition is characterized by the participation of ammophilous primary dune species including the vulnerable *Centaurea pumilio* at Falasarna.

The sclerophyllous shrubs (*Juniperus*, *Pistacia*, *Lycium*), which form the tall shrub layer (Pcaesp), are the dominant life form regarding cover. The layer of Chamaephytes is less developed compared to all other communities, except A2, but it includes the only reptile plant in this category, the sand binder *Medicago marina* and also the fruticose primary dune species *Euphorbia paralias*. The herb layer is dominated by annuals, but perennial plants, especially rhizomatous geophytes, which include the sand binder *Elytrigia juncea* and the primary dune species *Eryngium maritimum* and *Sporobolus pungens* have an increased participation compared to other groups. Regarding moisture, the floristic composition is similar to other groups, with a dominance of plants of dry to extremely dry sites but with more plants of fresh to damp sites, which include *Sporobolus pungens*, *Pancratium maritimum* and *Cakile maritima*. Regarding nutrients, the participation of plants of intermediate and rich sites (values 5 to 8) is increased.

These are mainly ammonitrophilous drift line plants and pioneer and ammophilous plants rather than synanthropic vegetation plants and include the nitrophilous halotolerant shrub *Lycium schweinfurthii*. Regarding salt, the very halotolerant plants are dominant and there is the highest participation of meso- to euhaline plants.

The analysis of the 3m x 3m plots demonstrated very similar results and therefore they are not presented separately.

5.2.2 Ecological analysis

The exploratory DCA of all 38 plots (Figure 7, Table 4) resulted in a modest unimodal response in the first 2 axes which revealed two strong gradients. The sites were ordered along the main gradient of the 1st axis from the foredune communities on the left (comm. B3) to the stabilized inner deep dune communities (comm. B2, B1) and shallower dune communities (comm. A1) on the right. This gradient may represent geomorphological variables or an increase in soil moisture and decrease in salinity. Along the 2nd axis the sites were ordered roughly according to the site, Elafonisi on top, Gavdos and Falasarna in the middle and Chrysi at the bottom. This gradient apparently represents differences among the sites which are partly due to the presence of species with narrow distribution (such as *Nigella stricta*, *Silene succulenta*, *Periploca angustifolia*) and to the fact that two of the sites are small islands isolated from the mainland. It may also partly represent a disturbance gradient as indicated by the presence of many annuals and grasses at the top left side of the graph.

Further analysis on ecological gradients was made on all plots excluding the two plots at Falasarna (36 plots) which due to the high disturbance of the area and to the fragmentation of the habitat are outliers.

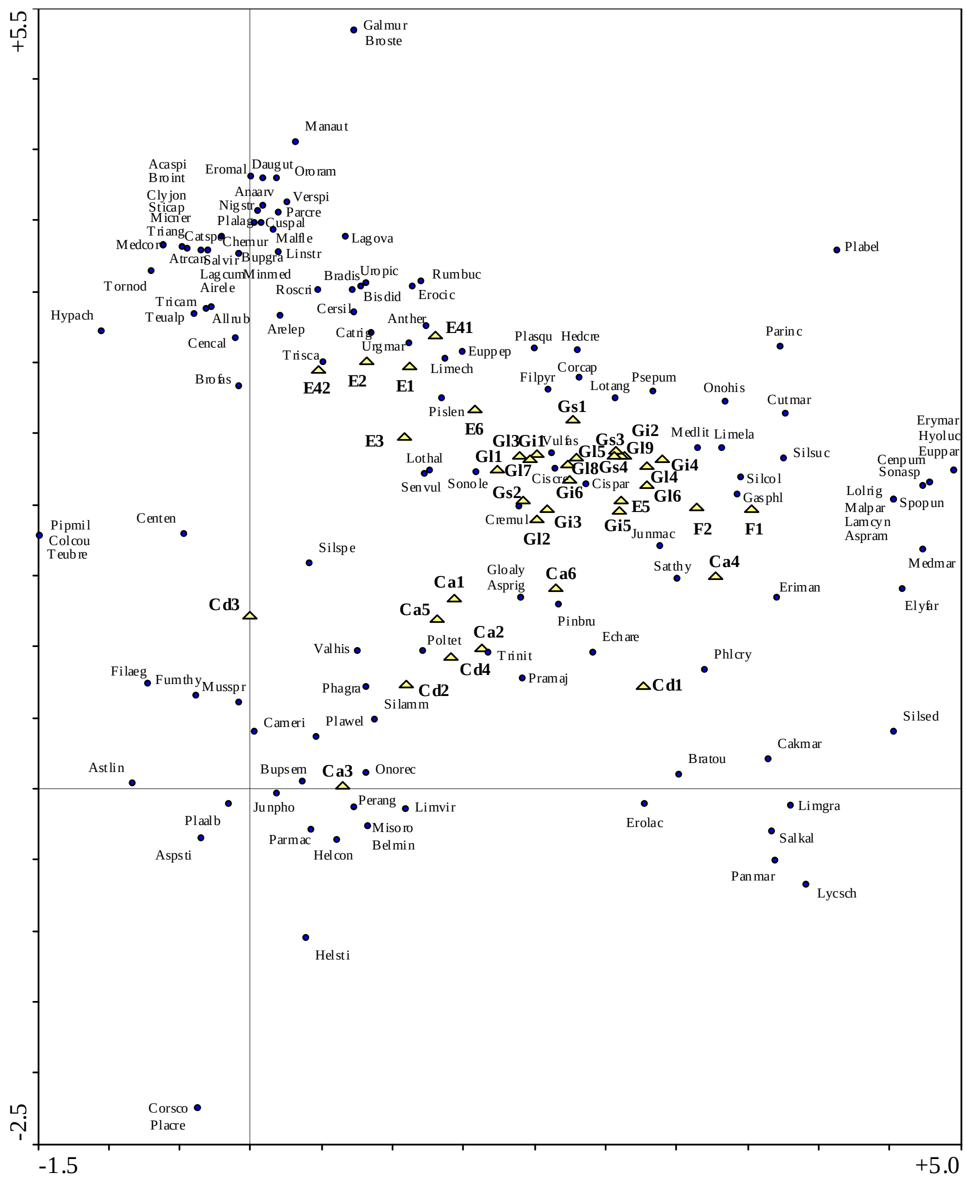


Figure 7 DCA of all plots (38 plots, 133 species), axes 1 and 2, symmetric biplot scaling. Triangles: sites; circles: species.

Table 4 Summary of DCA of all plots (38 plots, 133 species)

Axes	1	2	3	4
Eigenvalues	.465	.317	.170	.136
Lengths of gradient	3.518	3.210	2.400	2.111
Cumulative percentage variance of species data	10.8	18.2	22.2	25.3
Total inertia (Sum of all unconstrained eigenvalues)	4.290			

The exploratory DCA for the 36 plots resulted in a modest unimodal response (lengths of gradient for the first 2 axes 3.518 and 3.210, respectively), so CCA was used for the investigation of relations between environmental variables, species and sites (Figure 8, Table 5). The relationships between species data and environment data were assessed graphically and also by the weighted averages of the species with respect to environmental variables (the species with the top ten weighted averages were considered as candidates for indicator species).

The environmental variables explaining better the species data were the <u>geomorphological ones (substrate, dune-interdune depth and slope) and the anthropogenic disturbances (grazing, plot use)</u>. The upper quadrants include sites on marl, mainly on Chrysi, and the lower sites on sandstone (left), mainly on Gavdos, and conglomerate (right) on Elafonisi. Dune-interdune depth and slope increase from top to bottom, with the deep dune sites of Chrysi and Gavdos at the bottom half of the diagram. On the contrary grazing and plot use increase from bottom right to top left, with the highly affected sites of Elafonisi at bottom right and the less disturbed sites of Chrysi at top right. *Juniperus macrocarpa* is located at the bottom left quadrant (increasing values for sandstone and dune depth) but close to the start of the axes along with the species that occur in many plots and are not highly affected by the environmental variables tested such as *Pseudorlaya pumila*, *Lotus halophilous* and *Pistacia lentiscus*. These species are candidates for keystone species due to their abundant and stable presence in the habitat. The species closely related to larger dune depths that are candidates for indicators of deep dunes and for their keystone species are those that characterize communities B2 (*Silene succulenta*, *Cutandia maritima*) and B3 (*Elytrigia juncea*, *Medicago marina*) and also *Salsola kali, Cakile maritima* and *Lycium schweinfurthii*. *Juniperus phoenicea* is located at the upper quadrant since it occurs at shallower dunes along with *Periploca angustifolia* and *Ononis reclinata*. It is not an indicator of dunes on marls since it also occurs on sandstone. The species closely related to marls are *Paronychia macrosepala*, *Helianthemum stipulatum*, *Helichrysum conglobatum*, *Teucrium brevifolium*, *Plantago albicans* and *Colchicum coustourieri* and are candidates for indicators and for keystone species of shallow and moderate depth dunes on marl. The species closely related to conglomerates and higher rock cover are the characteristic species of community A2, *Malcolmia flexuosa* and *Nigella stricta*, and also the species *Minuartia mediterranea* and are candidates for indicator and keystone species. Other species in this quadrant with high weighted averages for conglomerate and rock cover are also closely related to grazing and/or plot use. Such species are *Galium murale*, *Bromus sterilis* and *Plantago bellardi* and can be used as indicators for the assessment of the conservation status of the plots. A list of candidate indicator and keystone species based on the CCA analysis and the vegetation analysis by the TWINSPAN is provided in Table 14.

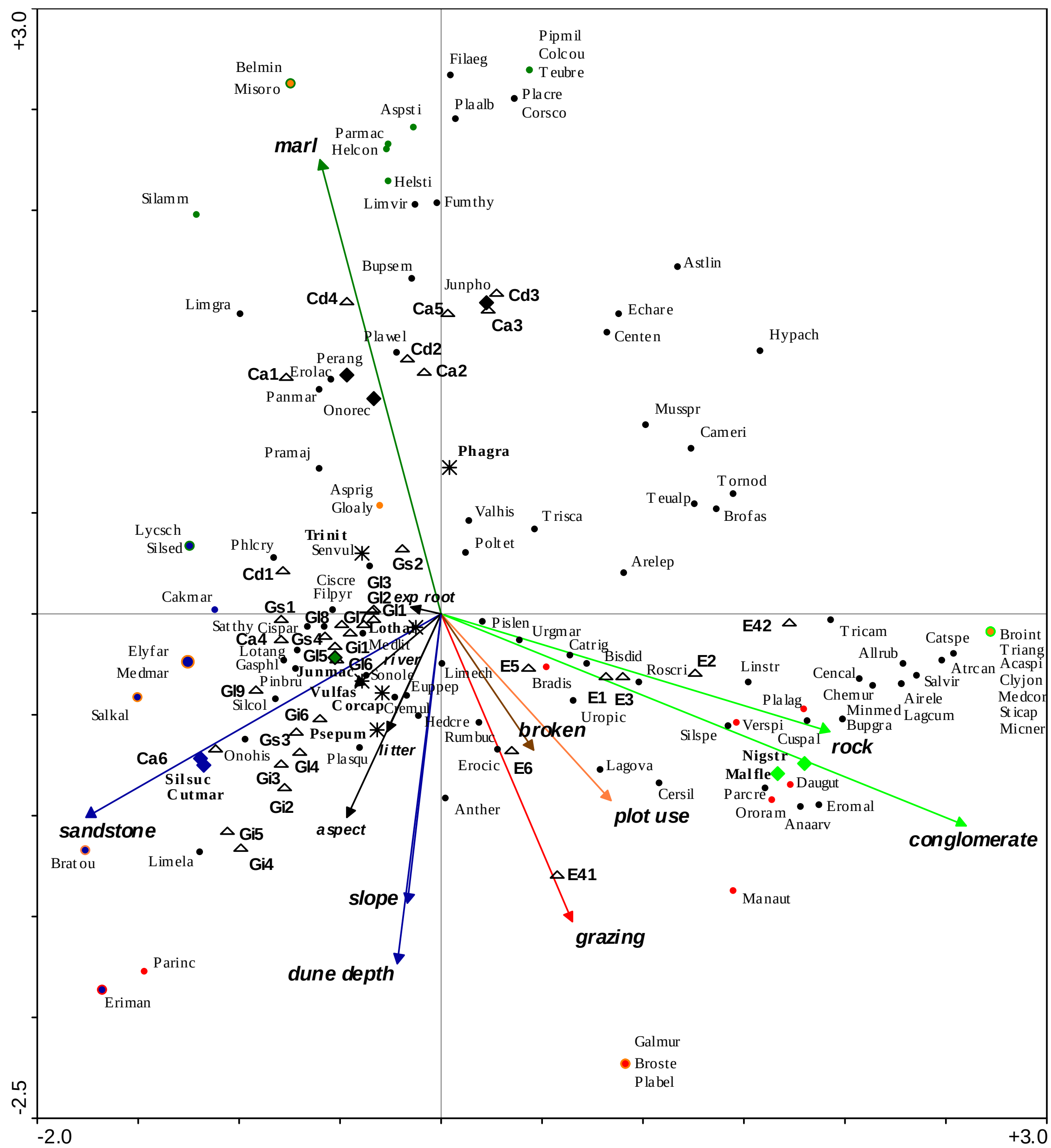


Figure 8 CCA of all plots (36 plots, 123 species), axes 1 and 2, symmetric biplot scaling. Triangles: sites; circles: species; diamonds: characteristic species of the vegetation communities; stars: most frequent species in all communities. Black arrows: variables with non significant contribution to the model; coloured arrows: variables with significant contribution to the model. Coloured species' points represent the species with a strong positive relation to the respective environmental variables (top 10 weighted averages of species with respect to the variable).

Table 5 Summary of CCA of all plots (36 plots, 123 species)

Axes *	1	2	3	4
Eigenvalues	.400	.342	.199	.183
Species-environment correlations	.977	.922	.893	.965
Cumulative percentage variance				
of species data	10.2	18.9	23.9	28.6
of species-environment relation	21.8	40.4	51.2	61.2
Sum of all unconstrained eigenvalues (total inertia)				3.930
Sum of all canonical eigenvalues				1.837

**P*= 0.005 for the 1st canonical axis and for the full model (Monte Carlo test)

Environmental Variable	Lambda1 Marginal effects	LambdaA Conditional effects	P
Conglomerate	0.37	0.37	0.0050
Dune depthxInterdune depth	0.20	0.20	0.0050
Grazing	0.19	0.16	0.0200
Plot use	0.18	0.14	0.0350
Marls	0.26	0.16	0.0050
Sandstone	0.25	0.06	0.8500
Slope	0.18	0.11	0.1300
Rock cover	0.24	0.10	0.4100
Broken branches per tree	0.16	0.18	0.4300
Exposed root cover	0.13	0.12	
Aspect	0.13	0.10	
Litter cover	0.08	0.07	
River terrace	0.07		

5.3 Transect data analysis

5.3.1 Vegetation groups

The hierarchical classification of the transect plot data resulted in roughly 18 community types. The results of the analysis are shown in Figure 9. The community types represent the spatial succession of sand dune communities from the sea landwards, but cannot be considered as communities in the phytosociological sense.

The transect plots were separated in four well distinguished large groups: **group C** - *Anthyllis hermaniae-Centaurea pumilio* (mostly Kedrodasos plots); **group D** - *Silene succulenta-Pancratium maritimum* (primary dunes and foredunes mostly Chrysi plots); and two *Silene succulenta-Pseudorlaya pumila* groups (primary dune and dune shrub), **group E** - *Juniperus macrocarpa* (juniper shrub, all sites); and **group F** *Ononis natrix-Coridothymus capitatus* (mostly Gavdos plots). *Silene succulenta*, *Triplachne nitens* and *Lotus halophilous* were the species with the highest frequency in all communities of all sites, except from Kedrodasos. The analysis further separated 27 subgroups (maximum dissimilarity 0.508). The plant communities identified based on the subgroups are presented below. The juniper shrub communities have been name in correspondence to the communities identified by the plot data analysis.

Group C

Community C1: (primary dune-2110, Kedrodasos, subgroups 1, 2): Flat dune with *Centaurea pumilio*, represents the first vegetation zone from the sea with very low cover and occasional presence of ammophilous plants, including also *Pancratium maritimum*.

Community C2: (dune shrub-2260, Kedrodasos, Gavdos-Agios Ioannis, subgroup 3): Dune shrub with *Anthyllis hermaniae-Coridothymus capitatus* with occasional presence of ammophilous plants, such as *Centaurea pumilio* and *Limonium elaphonesicum*. It represents the first vegetation zones from the sea, instead of the primary dune communities on shallow dunes - rocky substrate or behind front line of rocks.

Group D

Community D1: (primary dune-2110, Chrysi, subgroup 5): Primary dune with *Silene succulenta-Zygophyllum album*, which is a halophilous Mediterranean species occurring in arid and very arid bioclimate. The floristic composition is also characterized by the presence of the ammonitrophilous *Cakile maritima* and *Salsola kali* and of typical ammophilous plants including sand binders (*Elytrigia juncea*, *Medicago marina*). In addition, there is the stable participation a maritime rock plant which in the Aegean also acts as a sand binder, *Limonium graecum*, and the occasional but typical participation of the rare in Greece halophyte *Limoniastrum monopetalum*. Community D1 represents low deep and medium deep dune communities of the first vegetation zones mainly of the east part of Chrysi and also more inland communities at large shrub openings with moving sand. At the east part of Chrysi, D1 communities form a high cover narrow front zone and then a low and very low cover interim zone between primary dunes and foredunes with junipers.

Community B3.1: (foredune shrub-2250, Chrysi, subgroup 4): High dune with *Juniperus macrocarpa-Zygophyllum album*. It is similar to community D1 and corresponds to community type B3. It represents dune shrub on foredunes or more inward dunes at the margins of large shrub openings with moving sand.

Community D2: (primary dune-2110, Chrysi, Gavdos-Agios Ioannis, subgroup 7): Primary dune with *Silene succulenta-Euphorbia paralias*. It is a typical ammophilous community, including sand binders and also *Limonium graecum* and *Limoniastrum monopetalum* but lacking *Zygophyllum album* and the ammonitrophilous plants of community D2. It represents low deep and medium deep dune communities of the first vegetation zones at Chrysi (mainly west) and rarely more inland communities at large shrub openings with moving sand. At wetter places, *Juncus heldreichianus* participates in the community. At the west part of Chrysi these communities are well developed and form a wide high cover front zone.

Community D3: (primary dune grassland-2230, Chrysi, subgroups 8, 9): Dune grassland with *Triplachne nitens-Misopates orontium* is a low cover community of inland dunes and interdunes with loose sand.

Community D4: (primary dune slack-2190, Chrysi, subgroup 10): Dune slack with *Juncus heldreichianus*, at flat wet dunes, behind the first vegetation zone.

Community B3.2: (foredune shrub-2250, Chrysi, subgroup 11): High dune with *Juniperus macrocarpa-Pancratium maritimum*. It is similar to community D2 and corresponds to community type B3. It represents dune shrub on foredunes or more inward dunes at the margins of large shrub openings with moving sand.

Community A1.1: (hind dune shrub-2250, Chrysi, subgroup 6): Dune shrub with *Juniperus phoenicea-Asparagus stipularis*. It is a case of community A1 *Juniperus phoenicea-Periploca angustifolia* and occurs at inner dunes.

Group E

Community A2: (foredune or hind dune shrub-2250, Kedrodasos, subgroups 13, 14): Dune shrub with *Juniperus macrocarpa-Nigella stricta* and *Juniperus phoenicea-Nigella stricta*.

Community B2.1: (foredune or hind dune shrub-2250, Gavdos-Agios Ioannis, subgroup 15): Dune shrub with *Juniperus macrocarpa-Limonium elaphonesicum*. It is a case of the *Silene succulenta-Cutandia maritima* community B2 characterized by the participation of few ammophilous species, no sand binders, and also a lack of non-ammophilous species.

Community B2.2: (foredune or hind dune shrub-2250, Chrysi, Gavdos-Lavrakas, subgroup 23): Dune shrub with *Juniperus macrocarpa-Mercurialis annua*. It is also a case of community B2, characterized by a few ammophilous species but scarcely any sand binders and by the stable presence of synanthropic vegetation species, including *Mercurialis annua*. It represents inner dunes, highly disturbed by human use.

Communities B1/B2: (foredune or hind dune shrub-2250, *Chrysi, Gavdos*): Dune shrub with *Juniperus macrocarpa* non-attributable to a particular community due to the fact that the transect plots represent fragments of communities or communities of transition zones. These have been preliminarily attributed to community types B1 or B2 as follows:

Community B1 (subgroups 12, 19, 20, 22, Gavdos-Lavrakas and Agios Ioannis): Dune shrub with *Juniperus macrocarpa* characterized by *Ononis natrix* and/or *Coridothymus capitatus* or by *Limonium elaphonesicum*, lacking *Silene succulenta* and *Cutandia maritima* and other ammophilous species.

Community B2 (subgroups 16, 17 Gavdos-Agios Ioannis and 18 Chrysi): Dune shrub with *Juniperus macrocarpa* alone or with *Cutandia maritima* or with *Limoniastrum monopetalum*.

Group F

Community F1: (primary dune 2110/2230, Gavdos-Agios Ioannis-Lavrakas, subgroup 24): Low cover dune vegetation with *Limonium elaphonesicum* (possibly as sand binder) and *Pseudorlaya pumila*. It represents the first vegetation zones.

Community F2: (subgroup 26) is characterized by the participation of *Silene succulenta-Pseudorlaya pumila* and a lack of other ammophilous and dry grassland species. It is divided in two sub-communities based on the presence of shrubs:

Sub-community F2.1: (foredune or hind dune shrub-2260, *Gavdos-Lavrakas*): *Ononis natrix-Coridothymus capitatus* shrub on semi-stabilized on stabilized dune behind the first vegetation zone and at interdunes.

***Sub-community F2.2*:** (primary dune grassland-2230, *Gavdos-Agios Ioannis*, Chrysi, Kedrodasos): *Silene succulenta-Pseudorlaya pumila* low cover communities mainly at large shrub openings of the inner zones.

Community B1: (foredune or hind dune shrub-2250, *Gavdos*-all sites, subgroup 25). Dune shrub with *Juniperus macrocarpa* characterized by *Ononis natrix-Coridothymus capitatus*.

Community F3: (subgroup 27) is characterized by the participation of *Silene succulenta-Pseudorlaya pumila* and also of the ammophilous species *Lotus halophilous*, *Medicago littoralis*, *Medicago marina*. It is divided in two sub-communities based on the presence of shrubs:

Sub-community F3.1: (foredune or hind dune shrub-2260, *Gavdos-all sites*, Kedrodasos): *Ononis natrix-Coridothymus capitatus* shrub on semi-stabilized on stabilized dune behind the first vegetation zone and at interdunes.

Sub-community F3.2: (primary dune-2110, *Gavdos-Sarakiniko, Agios Ioannis*): *Silene succulenta-Pseudorlaya pumila* low cover communities representing the first vegetation zone at Sarakiniko and large shrub openings of the inner zones at Agios Ioannis.

The spatial vegetation succession in the study sites, based on the transect data analysis and on the plot data analysis, is shown comprehensively in Table 6. On Chrysi there is a wide primary dune zone (high cover at the west part and low cover except from a front line at the east part) with typical ammophilous vegetation including sand binders, behind which the higher dunes, foredunes and then hind dunes, develop. At Kedrodasos the primary dune zone is restricted to narrow low cover communities, lacking the typical sand binders and higher foredunes with low shrub (2260) or juniper (2250) start abruptly. On Gavdos, the typical succession of primary dune-foredune-hind dune is seen only at Sarakiniko where the primary dune zone is extended but degraded with *Medicago marina* and possibly *Limonium elaphonesicum* as the main dune stabilizers. At Agios Ioannis and Lavrakas the first zones include low cover primary dune communities or low shrubs and subshrubs while at the rocky sites the juniper shrub foredunes start abruptly.

Table 6 Dune vegetation succession at the study sites

Dune zone	Chrysi	Kedrodasos	Agios Ioannis	Lavrakas	Sarakiniko
primary dune (incipient dune)	D1, D2, D3, D4, F2.2	C1, C2, F2.2	D2, F1, F2.2, C2	F1	F3.2
foredune	B3	C2, F3.1	C2	F3.1	
primary dune (interdune)	D1, D2, D3	C1, C2	F2.2, F3.2		
foredune or hind dune	B1, B2,	A2	B1, B2.1, F3.1	B1, B2.1, F2.1	B1, F3.1
hind dune	A1	B1, B2			B2

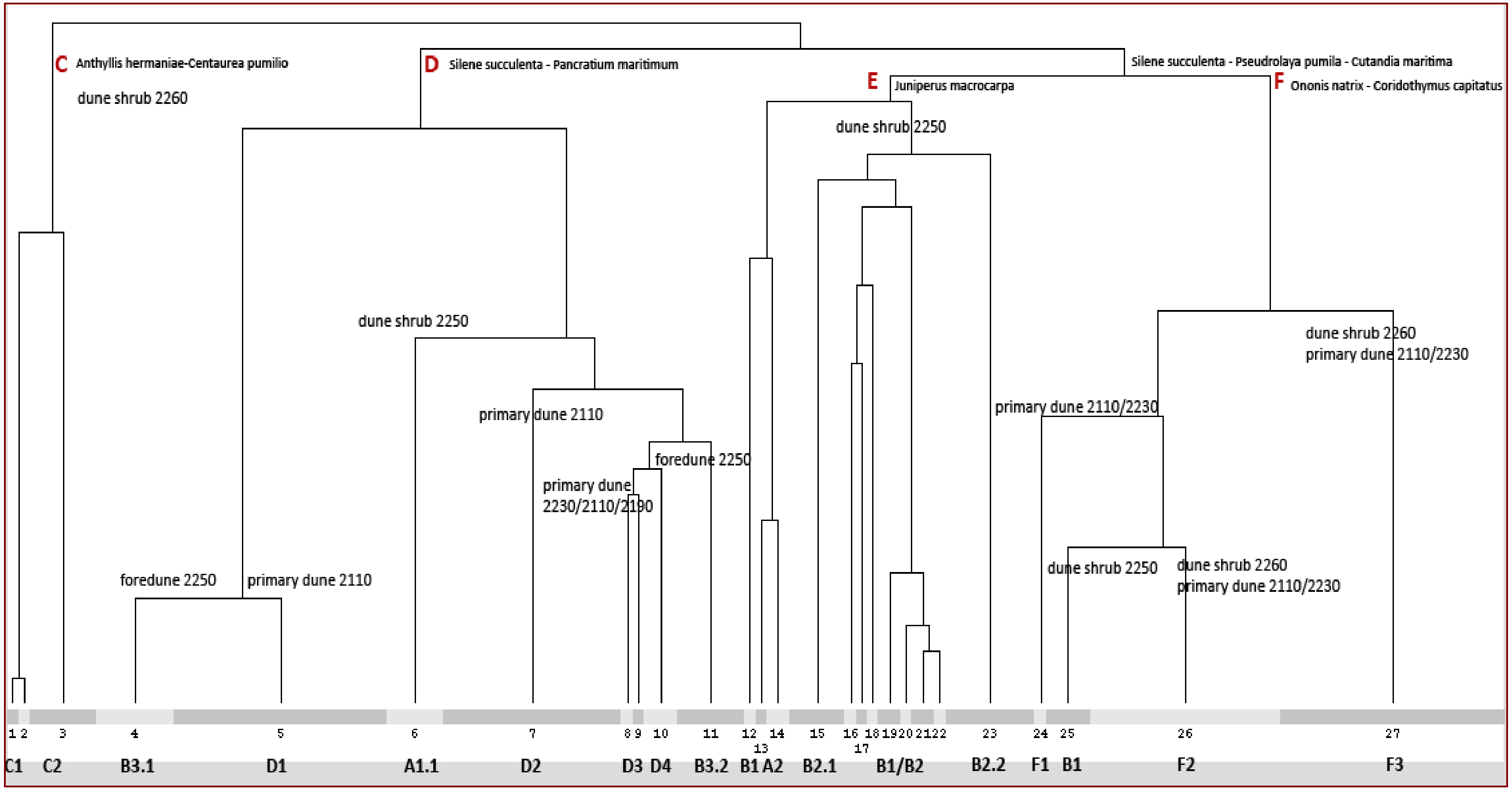


Figure 9 Hierarchical classification of the transect data. Primary dune communities (2110/2130/2190): C1, D1, D2, D3, D4, F1, and parts of F2 and F3; low shrub communities (2260): C2, F2, F3; juniper shrub communities (2250): A1, A2, B1, B2, B3 (as in vegetation classification)

5.3.2 Ecological analysis

The exploratory DCA of all 134 transect plots (Figure 10, Table 7) resulted in a strong unimodal response in the first 2 axes which revealed two strong gradients. The sites were ordered along the main gradient of the 1st axis according to the site, Elafonisi on the right, Gavdos in the middle and Chrysi on the left. This gradient apparently represents differences among the sites which are partly due to the different geomorphological variables among sites and partly due to the presence of species with narrow distribution and to the fact that two of the sites are small islands isolated from the mainland. Along the 2nd axis the sites were ordered roughly according to the spatial vegetation succession, with primary dune communities on top, low shrub foredune and hind dune communities in the middle and tall shrub foredune and hind dune communities from middle to bottom.

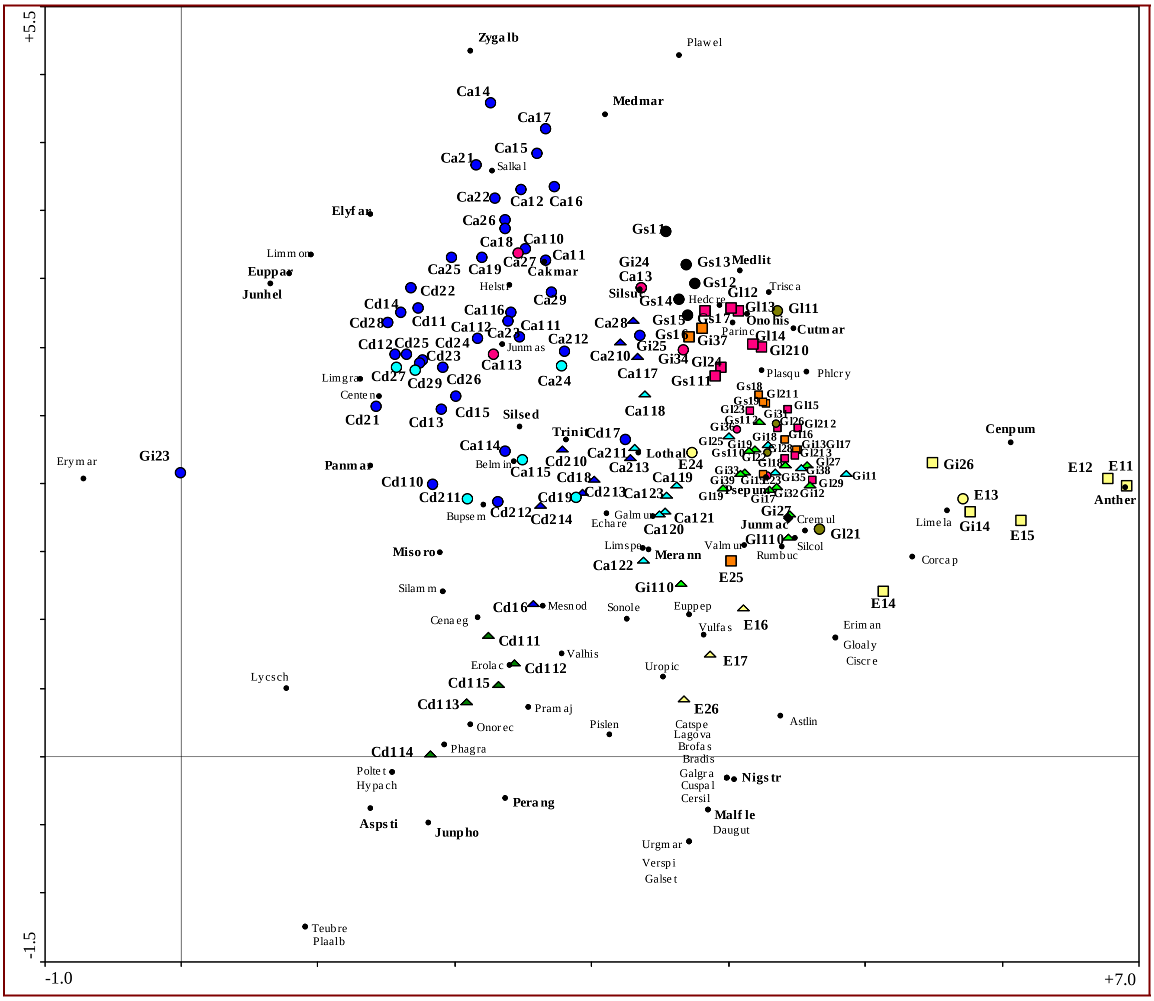


Figure 10 DCA of all transect plots (134 plots, 82 species), axes 1 and 2, symmetric Hill scaling. Black small circles: species. Triangles, large circles and squares: sites according to vegetation community as follows: A1= triangle, dark green; A2= triangle, yellow; B1= triangle, light green; B2= triangle, light blue; B3= triangle, dark blue; C1= circle, yellow; C2= square, yellow; D1= circle, dark blue; D2= circle, dark blue; D3= circle, light blue; D4= circle, light blue; F1= circle, brown; F2.1= square, rose; F2.2= circle, rose; F3.1= square, orange; F3.2= circle, orange.

Table 7 Summary of DCA of all transect plots (134 plots, 82 species)

Axes	1	2	3	4
Eigenvalues	.710	.527	.356	.280
Lengths of gradient	6.915	4.787	3.885	3.147
Cumulative percentage variance of species data	8.1	14.1	18.1	21.3
Total inertia (Sum of all unconstrained eigenvalues)	8.788			

Further analysis on ecological gradients was made for each site separately. The exploratory DCAs resulted in strong unimodal response (lengths of gradient for the first 2 axes > 4 and > 3, respectively), so CCA was used for the investigation of relations between environmental variables (altitude, distance from shore, inclination), species and sites (Figures 11, 12, 13, 14, Tables 8, 9, 10, 11). In all cases altitude, distance from shore and inclination, in order of significance, influenced the floristic composition. The models explained a high percentage of the species-environment relation but a low percentage of the species variance indicating that other environmental variables play a significant role, too. The graphs illustrate the spatial vegetation zonation at each site.

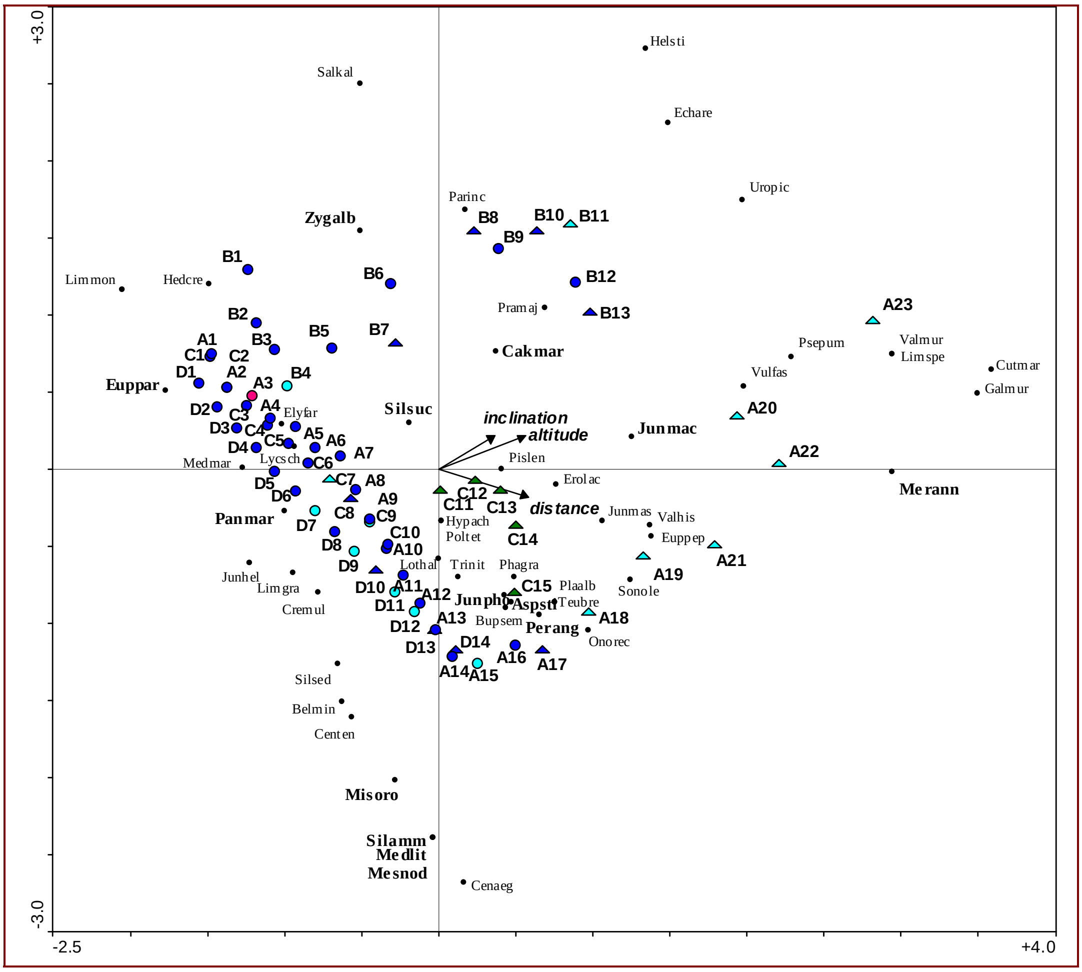


Figure 11 CCA of Chrysi transect plots, axes 1 and 2, symmetric Hill scaling. Black small circles: species. Triangles, large circles and squares: sites according to vegetation community as in Figure 10.

Table 8 Summary of CCA of Chrysi transect plots

Axes *	1	2	3	4
Eigenvalues	.433	.197	.059	.534
Species-environment correlations	.934	.714	.663	.000
Cumulative percentage variance				
of species data	9.4	13.6	14.9	26.4
of species-environment relation	62.8	91.4	100.0	.0
Sum of all unconstrained eigenvalues (total inertia)	4.630			
Sum of all canonical eigenvalues	.690			

**P*= 0.005 for the 1st canonical axis and for the full model (Monte Carlo test)

Environmental Variable	**Lambda1 Marginal effects**	**LambdaA Conditional effects**	**P**
distance	0.41	0.41	0.0050
altitude	0.40	0.21	0.0050
inclination	0.21	0.07	0.4300

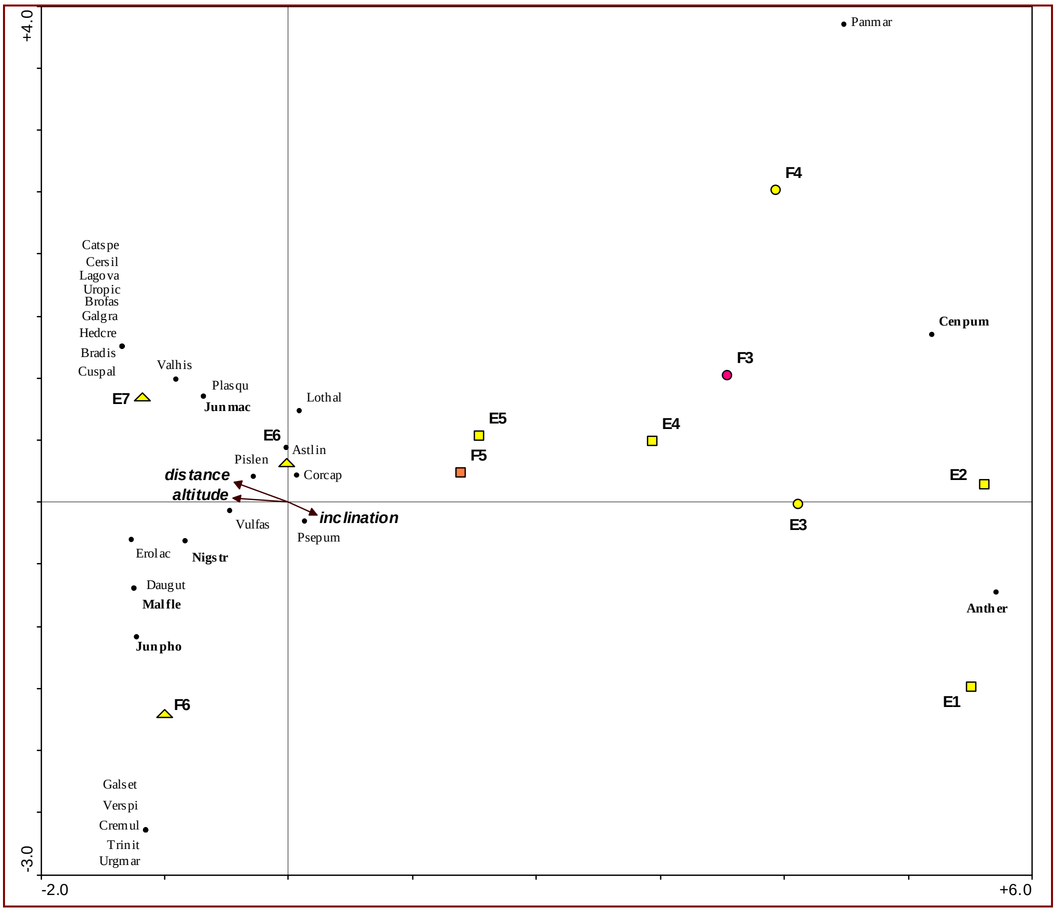


Figure 12 CCA of Kedrodasos (Elafonisi) transect plots, axes 1 and 2, symmetric Hill scaling. Black small circles: species. Triangles, large circles and squares: sites according to vegetation community as in Figure 10.

Table 9 Summary of CCA of Kedrodasos (Elafonisi) transect plots

Axes *	1	2	3	4
Eigenvalues	.769	.428	.112	.623
Species-environment correlations	.946	.953	.529	.000
Cumulative percentage variance				
of species data	28.3	44.0	48.1	71.0
of species-environment relation	58.8	91.5	100.0	.0
Sum of all unconstrained eigenvalues (total inertia)	2.721			
Sum of all canonical eigenvalues	1.308			

**P*= 0.005 for the 1st canonical axis and for the reduced model (Monte Carlo test), *P*= 0.015 for the full model

Environmental Variable	**Lambda1 Marginal effects**	**LambdaA Conditional effects**	**P**
distance	0.76	0.76	0.0050
altitude	0.74	0.41	0.1250
inclination	0.29	0.14	0.6450

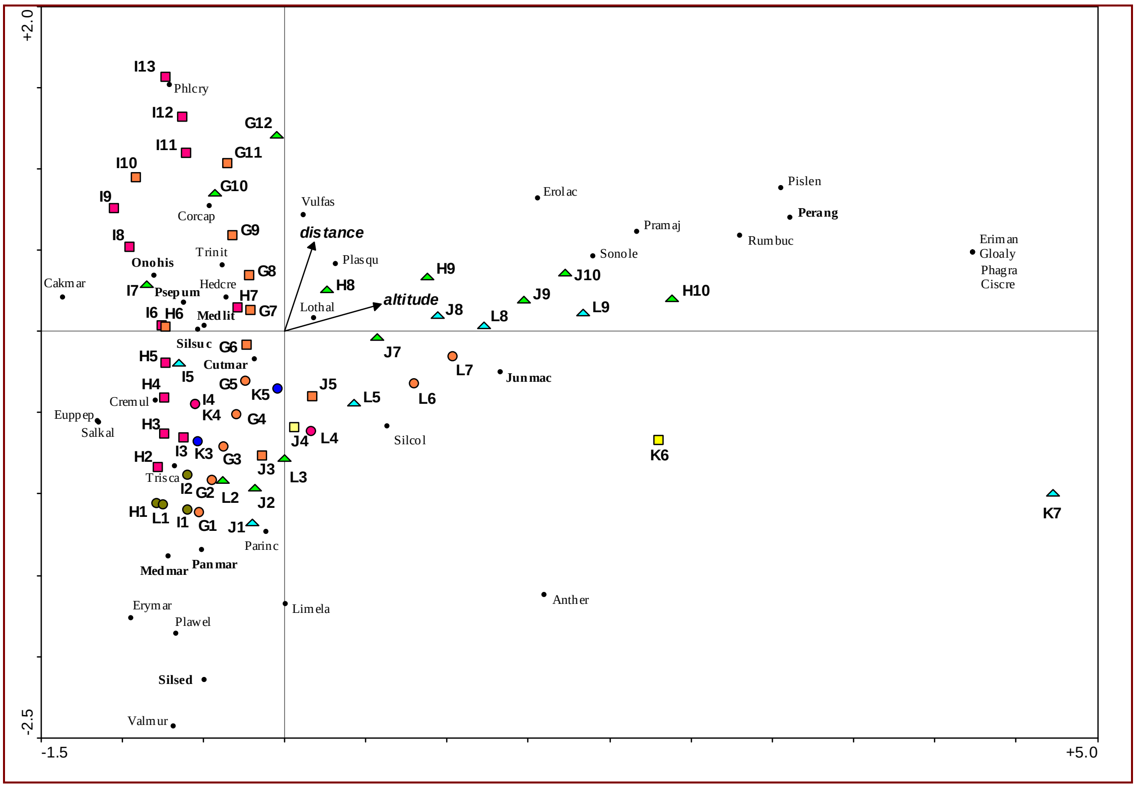


Figure 13 CCA of Gavdos transect plots, axes 1 and 2, symmetric Hill scaling. Black small circles: species. Triangles, large circles and squares: sites according to vegetation community as in Figure 10.

Table 10 Summary of CCA of Kedrodasos (Elafonisi) transect plots

Axes *	1	2	3	4
Eigenvalues	.317	.147	.852	.453
Species-environment correlations	.861	.705	.000	.000
Cumulative percentage variance				
of species data	7.0	10.2	29.0	39.0
of species-environment relation	68.3	100.0	.0	.0
Sum of all unconstrained eigenvalues (total inertia)	4.540			
Sum of all canonical eigenvalues	.465			

*P= 0.005 for the 1st canonical axis and for the full model (Monte Carlo test)

Environmental Variable	**Lambda1 Marginal effects**	**LambdaA Conditional effects**	**P**
altitude	0.30	0.30	0.0050
distance	0.16	0.16	0.0050

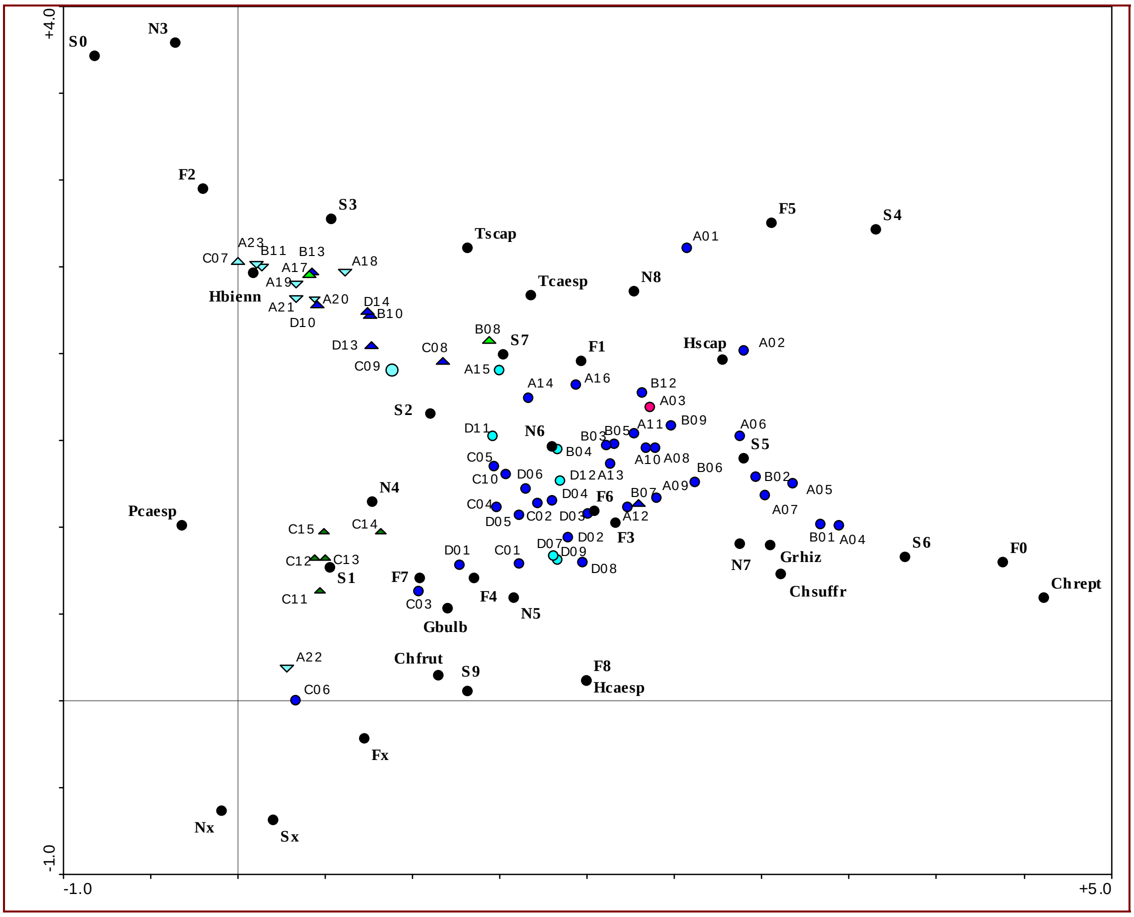


Figure 14 DCA of Chrysi transect plots showing the ordination of life forms and Ellenberg values for moisture (F), nutrients (N), and salt (S) (65 plots, 43 species-characters). The percent cover of plants of each character was used as species' value for each plot. Black large circles: characters. Triangles, large circles and squares: sites according to vegetation community as in Figure 10.

Table 11 Summary of DCA of Chrysi transect plots (65 plots, 43 species-characters)

Axes	1	2	3	4
Eigenvalues	.527	.295	.177	.128
Lengths of gradient	3.442	2.605	3.914	2.396
Cumulative percentage variance of species data	21.0	32.7	39.8	44.8
Total inertia (Sum of all unconstrained eigenvalues)	2.512			

The floristic composition of the communities identified regarding life forms and Ellenberg values for moisture, nutrients, and salt at each site was explored with DCA for Chrysi and Gavdos and with PCA for Elafonisi-Kedrodasos (because of the small, 2.916, lengths of gradient in the exploratory DCA for the latter) (Figures 14, 15, 16, Tables 11, 12, 13).

The plots of Chrysi (Figure 14, Table 13) were ordered along the major gradient of the 1st axis from the primary dune D1 communities on the right to D2, D3 and D4 communities in the middle and to the juniper shrub communities on the left. D1 communities are characterized by rhizomatous geophytes (e.g. *Elytrigia juncea*) and by suffruticose (e.g. *Zygophyllum album*) and reptile (e.g. *Medicago marina*) Chamaephytes. The salt values (S5, S6) are typical of plants tolerating medium to high chlorides or subjected to medium to high aero-haline stress (from sea spray). The nutrient values (N7) indicate plants of more or less rich sites (e.g. *Zygophyllum album*, *Limonium graecum*). Some plots are distinguished by high participation of plants indicating nutrient rich sites (N8, e.g. *Cakile maritima*, *Salsola kali*) and are separated along the 2nd axis. Plants of extremely dry sites (F0) such as *Zygophyllum album* also characterize this community. Some D1 community plots and most of D2, D3, and D4 community plots are gathered at the middle of the graph with moisture values ranging from very dry (F1, e.g. *Silene succulenta*) to dry (F3, e.g. *Elytrigia juncea*) and to fresh or damp sites (F6, e.g. *Parapholis incurva*). The plots with the caespitose *Juncus heldreichianus*, an indicator of damp to wet sites, are gathered at lower positions along the 2nd axis. D2, D3 and D4 communities include species with intermediate nutrient values with high to very high tolerance to salt stress (S7) and the plots with the halophytic fruticose *Limoniastrum monopetalum* (S9) are separated at lower parts along the 2nd axis. The juniper shrub A1 community plots are roughly separated from the B2 and B3 communities along the 2nd axis, based on the increased participation of low shrubs (Chfrut) and of slightly halotolerant plants (S1) at the former and of hemicryptophytes, annuals and of very halotolerant (S3) to halphobe plants (S0) at the latter. Regarding nutrients, most of their species are indicators of poor to intermediate rich sites.

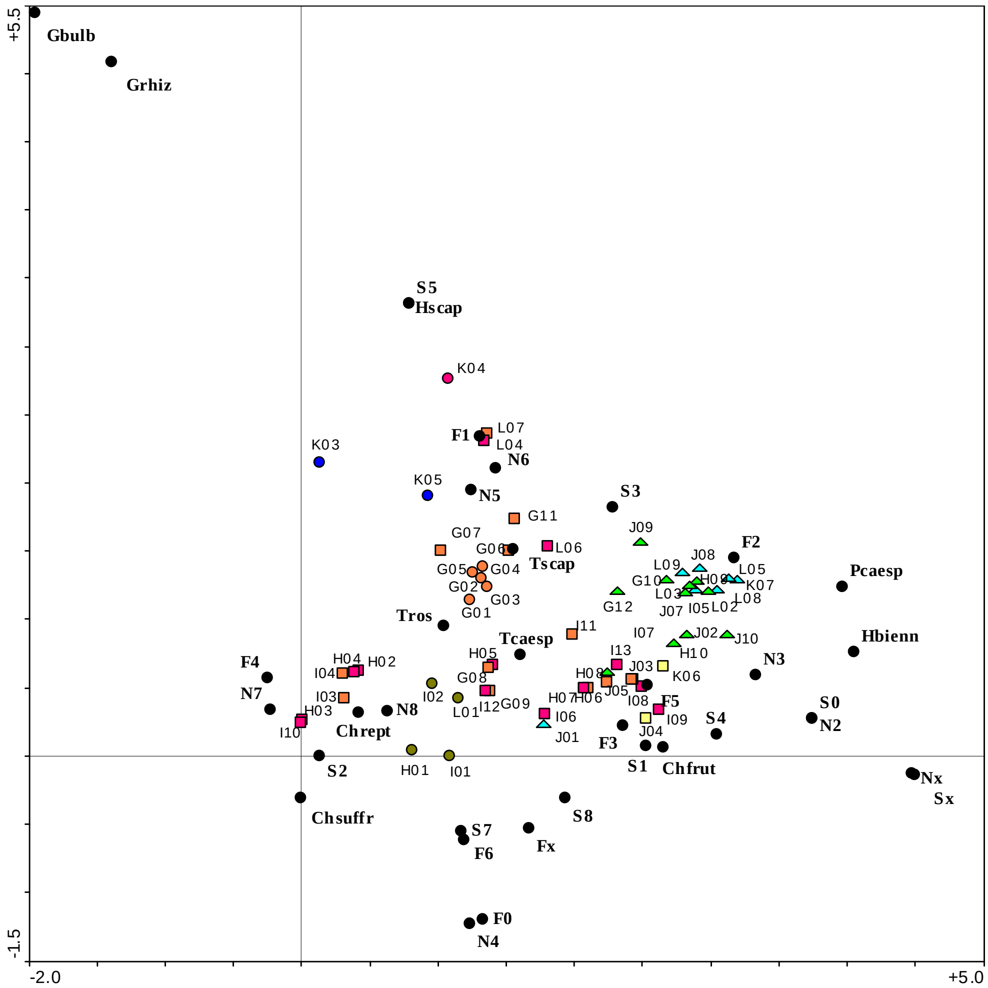


Figure 15 DCA of Gavdos transect plots showing the ordination of life forms and Ellenberg values for moisture (F), nutrients (N), and salt (S) (65 plots, 43 species-characters). The percent cover of plants of each character was used as species’ value for each plot. Black large circles: characters. Triangles, large circles and squares: sites according to vegetation community as in Figure10.

Table 12 Summary of DCA of Gavdos transect plots (65 plots, 43 species-characters)

Axes	1	2	3	4
Eigenvalues	.492	.283	.138	.078
Lengths of gradient	3.191	2.767	2.557	2.715
Cumulative percentage variance of species data	20.8	32.8	38.6	41.9
Total inertia (Sum of all unconstrained eigenvalues)	2.365			

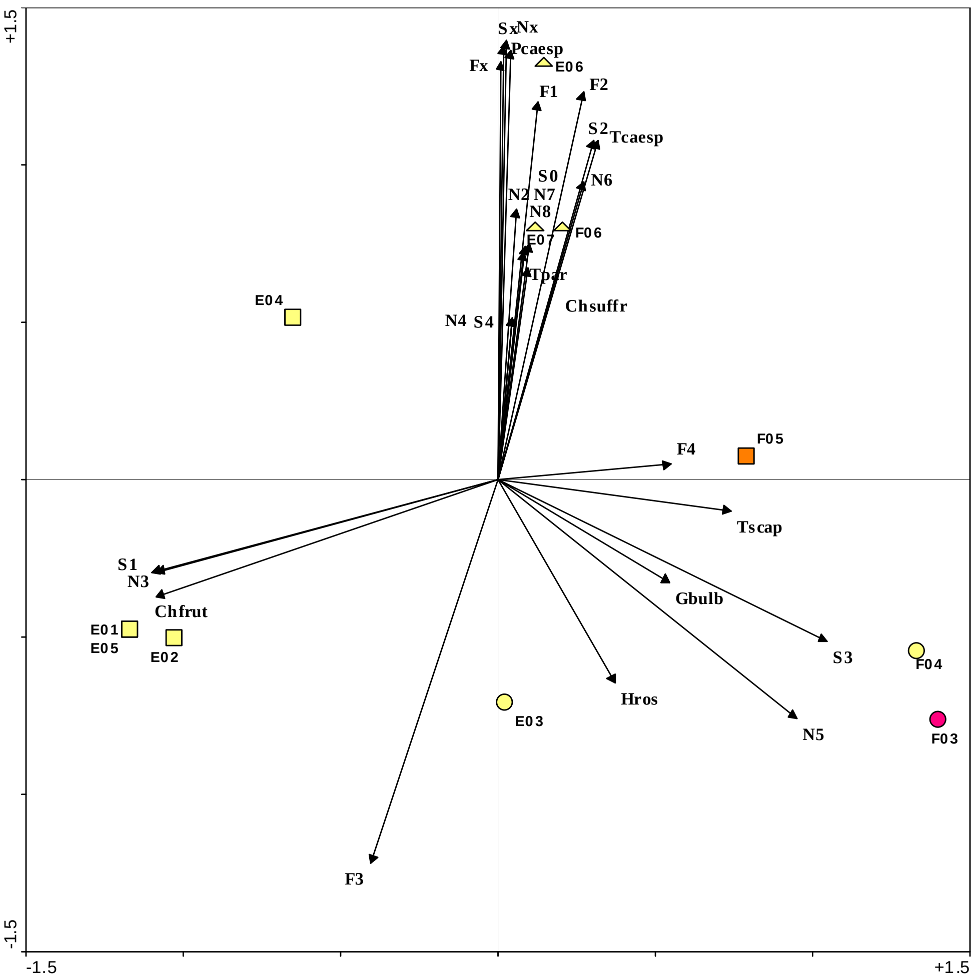


Figure 16 PCA of Elafonisi-Kedrodasos transect plots showing the ordination of life forms and Ellenberg values for moisture (F), nutrients (N), and salt (S) (65 plots, 43 species-characters). The percent cover of plants of each character was used as species' value for each plot. Black large circles: characters. Triangles, large circles and squares: sites according to vegetation community as in Figure10.

Table 13 Summary of PCA of Elafonisi-Kedrodasos transect plots (65 plots, 43 species-characters)

Axes	1	2	3	4
Eigenvalues	.616	.235	.101	.029
Cumulative percentage variance of species data	61.6	85.1	95.1	98.1
Total inertia (Sum of all unconstrained eigenvalues)	1.000			

At Kedrodasos (Figure 16, Table13), the primary dune plots with communities C1 and F2.2 are gathered at the bottom left quadrant characterized by the rosette forming *Centaurea pumilio* and by halotolerant plants of intermediate nutrient rich sites. The low shrub (Chfrut) community C2 at the bottom left quadrant is characterized by slightly halotolerant plants of nutrient poor sites (plot E04 is separated due to the presence of *Pistacia lentiscus*, Pcaesp). The juniper shrub community A2 at the upper left quadrant is characterized by halophobe to medium halotolerant plants and by plants of intermediate to rich sites regarding nutrients.

The plots of Gavdos (Figure 15, Table 12) were ordered along the major gradient of the 1st axis from the primary dune and foredune communities F1, F2, F3 on the left to the juniper shrub communities B1 and B2 on the right. The F2.1 and F3.1 communities are intermingled and their plots are ordered along the 1st axis. On the left are the plots characterized by the participation of the suffruticose *Ononis natrix* and the reptile chamaeophyte *Medicago marina*, of plants of more or less nutrient rich sites and of medium to very halotolerant or aero-haline plants. On the right are the plots characterized by the participation of the fruticose *Coridothymus capitatus* (and also of *Anthyllis hermaniae*, community C2), of plants of nutrient poor sites and of less halotolerant to halophobe plants. The F1 *Limonium elaphonesicum* (Chsuffr) community is separated from the other primary dune communities (D2, F2.2, F3.2) which are characterized by *Silene succulenta* (Hscap) and by geophytes (D2).

5.4 Keystone and Indicator species

The identification of keystone species for the habitat 2250 and of indicator species for the geomorphological characteristics and the quality of the habitat regarding plot use and grazing was based on the results of the plot and transects data analysis.

The indicator species were selected by the CCA analysis. An additional CCA for the Chrysi plot data and RDAs for Kedrodasos and Gavdos plot data were performed (data not shown) in order to investigate in better detail the relation of species and environmental variables. The species with the top 10 positive weighted averages with respect to each variable were selected as showing positive relation and the species with the bottom 10 negative weighted averages were selected as showing negative relation. The general literature for each species was taken into account for the final selection (i.e., obviously generalist species were excluded).

The criteria for the selection of keystone species were:

1. The species that were identified as characteristic (diagnostic and/or constant) of the vegetation communities by the TWINSPAN analysis.
2. The most frequent species in habitat 2250, i.e. those occurring in more than 40 % of all the 2250 plots.
3. The species that were identified as indicators of the geomorphological environmental variables (marl, sandstone, conglomerate, dune depth).
4. The set of keystone species should contain representatives of all the functional attributes (life form, pubescence, succulence, nitrogen fixing, sand fixing).

A set of 36 keystone species (32 for the habitat 2250) and a set of 80 indicator species were identified (Table 14). Both sets can be used for the assessment of habitat quality.

Table 14 List of keystone and indicator species. Keystone species are indicated by the habitat at which they are keystone. Indicator species are indicated by a sign at column of the respective environmental value. Characteristic (diagnostic/constant) species are indicated by the vegetation community they characterize.
+ : indicators of increased values of the environmental variable; - : indicators of decreased values of the environmental variable; *: indicator of extremely nutrient-rich sites (C/N 8-11, C/P<1, >6.0 mg P2O5/100g); **: indicator of increased plot use as outhouse. dd: dune depth; ma: marl; sa: sandstone; co: conglomerate; pu: plot use; gr: grazing

Taxon	Keystone species (habitat)	Frequency in habitat 2250 (83 plots)	Frequency in habitat 2250 %	Characteristic species (habitat)	Indicator species (environmental variable)					
					dd	ma	sa	co	pu	gr
Acanthus spinosus		1	1						+	
Aira elegantissima ssp. elegantissima		3	4					+		-
Allium rubrovittatum		2	2					+		-
Anthyllis hermanniae	2260	10	12	C2						
Asparagus stipularis	2250	9	11	A1.1	+	+				
Asperula rigida		1	1		-	+			+	-
Asterolinon linum-stellatum		4	5		-					-
Bellium minutum		2	2		+				+	-
Brachypodium distachyon		9	11							+
Brassica tournefortii		1	1		+		+		+	
Bromus intermedius		2	2						+	
Bromus sterilis		1	1						+	+
Bupleurum semicompositum		7	8							-
Cakile maritima	2250	19	23	D1, B3.1	+					
Centaurea pumilio	2250, 2110-Kedrodasos	2	2	B3, C1, C2						
Centranthus calcitrapae		4	5					+		-
Ceratonia siliqua		7	8					+		-
Chenopodium murale		3	4						*	
Cistus parviflorus		3	4				+		-	
Clypeola jonthlaspi		1	1						+	
Colchicum cousturieri		1	1		-	+			-	-
Coridothymus capitatus	2250	**35**	**42**	B1, C2, F2.1, F3.1						
Coronilla scorpioides		1	1		-	+			-	-
Cutandia maritima	2250	17	20	B2	+		+			
Daucus guttatus		7	8					+		+
Elytrigia juncea	2250	9	11	B3	+		+		+	
Erica manipuliflora		6	7		+		+		-	+

Taxon	Keystone species (habitat)	Frequency in habitat 2250 (83 plots)	Frequency in habitat 2250 %	Characteristic species (habitat)	Indicator species (environmental variable)					
					dd	ma	sa	co	pu	gr
Erodium cicutarium		15	18		+					
Euphorbia paralias	2110-Chrysi	3	4	D2						
Euphorbia peplus		17	20						+	
Filago aegaea ssp. aegaea		3	4		-	+				
Filago pyramidata		1	1				+		-	
Fumana thymifolia		6	7							-
Galium murale		4	5		+	+			+	
Globularia alypum		4	5		-	+			+	
Hedypnois cretica		26	31		+					-
Helianthemum stipulatum	2250	4	5	A1		+			-	-
Helichrysum conglobatum		6	7			+				-
Hypochaeris achyrophorus		3	4		-					-
Juncus heldreichianus	2190-Chrysi	0	0	D4						
Juniperus macrocarpa	2250	**69**	**83**	A2, B1, B2, B3						
Juniperus phoenicea	2250	25	30	A1						
Lagurus ovatus		12	14		+					
Limoniastrum monopetalum	2250	1	1	D (1,2), B3 (1,2)						
Limonium echioides		12	14						-	
Limonium elaphonisicum	2250, 2260-Gavdos	2	2	B2.1, F1	+					
Limonium graecum ssp. graecum	2250	9	11	D (1,2), B3 (1,2)		+			+	-
Limonium virgatum		1	1			+				-
Lotus angustissimus		1	1				+		-	
Lotus halophilus	2250	**51**	**61**	F3.1, F3.2					-	-
Lycium schweinfurthii		3	4		+				+	-
Malcolmia flexuosa	2250-Kedrodasos	7	8	A2				+		-
Mandragora autumnalis		3	4					+		+
Medicago coronata		1	1						+	
Medicago littoralis	2260	20	24	F3.1, F3.2						
Medicago marina	2250, 2260, 2110-Sarakiniko,	3	4	B3, F3.1, F3.2	+		+		+	
Mercurialis annua		8	10	B2.2					**	
Minuartia mediterraneae		1	1							
Misopates orontium		5	6	D3		+			+	
Muscari spreitzenhoferi	2250	11	13	A1, A2						
Nigella stricta	2250-	9	11	A2	+			+		

Taxon	Keystone species (habitat)	Frequency in habitat 2250 (83 plots)	Frequency in habitat 2250 %	Characteristic species (habitat)	Indicator species (environmental variable)					
					dd	ma	sa	co	pu	gr
	Kedrodasos,									
Ononis natrix ssp. hispanica	2250, 2260-Gavdos,Chrysi	17	20	B1, F2.1, F3.1			+			
Orobanche ramosa		7	8					+		+
Pancratium maritimum	2250	17	20	D, B3.2						-
Parapholis incurve		10	12				+			
Parietaria cretica		4	5					+		
Paronychia macrosepala		4	5							-
Periploca angustifolia	2250	16	19	A1						
Phagnalon graecum	2250	35	**42**	A1						-
Phleum crypsoides		9	11						+	
Pinus brutia		8	10		-					
Piptatherum miliaceum		3	4		-	+			-	-
Pistacia lentiscus	2250	**38**	**46**							-
Plantago albicans		6	7			+			-	-
Plantago bellardii ssp. bellardii		4	5						+	+
Plantago cretica		1	1		-	+			-	-
Plantago lagopus		3	4					+		+
Plantago squarrosa		30	36							+
Plantago weldenii		6	7							-
Prasium majus	2250	28	34	A1, B1						-
Pseudorlaya pumila	2250	**43**	**52**	F2.2, F3.2						
Salsola kali	2250	5	6	D1, B3.1	+				+	-
Satureja nervosa		1	1						+	
Silene ammophila ssp. ammophila		3	4		+	+				-
Silene colorata	2250	21	25	B1						
Silene sedoides		7	8		+				+	-
Silene succulenta	2250	**41**	**49**	B2, D1	+		+			
Sonchus oleraceus		25	30						+	+
Stipa capensis		1	1						+	
Teucrium brevifolium		6	7		-	+			-	-
Torilis nodosa		2	2		-					
Trifolium angustifolium		1	1						+	
Triplachne nitens	2250	**49**	**59**	D3						
Valantia hispida	2250	**37**	**45**	A1						
Verbascum spinosum		3	4							+
Vuplia fasciculata	2250	**43**	**52**							
Zygophyllum album	2250	6	7	D1, B3.1						

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Glossary of terms

Ammonitrophilous: Species that thrives in or prefers to grow in sandy habitats rich in nitrogen

Ammophilous: Species that thrives in or prefers to grow in sandy habitats.

Annual plants: plant with an annual (1 year, 1 season) life cycle

Chamaephyte: Low-growing perennial plants whose perennating buds or shoot apices are borne close to the ground (up to half a meter from the surface).

Euhaline plants: Species that can grow in water with salinity ranging 30 and 40 parts per thousand of dissolved salts; that is, in most cases, normal sea water.

Foredunes: The front line of coastal dunes or ridges that are parallel to the coastline and are stabilized by vegetation, they represent the development of primary dunes at favourable conditions.

Fruticose: Plant having a perennating stem that is woody above the base (with woody stems and branches); shrub.

Generalist species: Species that are able to thrive in a wide variety of environmental conditions and can make use of a variety of different resources

Geophyte: A perennial plant that survives the unfavorable period by means of underground food storage organs (bulb, corm, tuber, rhizome) from which the renewal buds arise.

Halophilous species: Species that thrives in or prefers to grow in the presence of salt

Halophobe species: Species that is intolerant in salt

Halophyte: Terrestrial plant that is adapted to grow in salt rich soils and salt laden air.

Halotolerant species: Species that is capable of living in a saline environment.

Hemicryptophyte: Perennial or biennial plant whose renewal buds remain at ground level during the unfavorable period. There the buds can be protected by the glumes and, in the winter, by dead leaves and the snow cover.

Hind dunes-secondary dunes: Dunes that develop at the back of and are protected from the foredunes.

Interdunes: Areas of moving sand among stabilised dunes

Indicator species: Species whose presence is directly related to a particular quality in its environment at a given location.

Indifferent species: Species that are not affected by a certain environmental condition.

Keystone species: Species that can occur at any trophic level and plays a critical role in maintaining a community because it has profound and far-reaching effects in the web of interactions and its removal would lead to significant changes (just like the removal of the keystone of an arch).

Mature dunes: Stabilized dunes with shrub or tree vegetation.

Mesohaline species: Species that can grow in water with salinity ranging 5-18 parts per thousand.

Nitrophilous species: Species that thrives in or prefers to grown in nitrogen rich habitats

Perennial plant: Plant with a perennial (more than 2 years) life cycle.

Phanerophyte: Plants whose perennating buds or shoot apices are borne on aerial shoots.

Primary dunes: The dunes formed by the first perennial plants that occur above the intertidal zone and form an obstacle for the accumulation of sand.

Sclerophyllous vegetation (species): Woody vegetation which consists of species with evergreen, hard, thick, leathery, and usually small leaves These adaptations allow the plants to survive the pronounced hot, dry season of the Mediterranean-type climate in which sclerophyllous vegetation is best developed.

Specialist species: Species that are able complete their life cycle in a narrow range of environmental conditions (a narrow niche).

Suffruticose plant: Plant having a perennating stem that is woody only at the base; subshrub

Therophyte: Annual species which survives unfavorable seasons in the form of seeds, and completes its life-cycle during favorable seasons.

Plant community: A group of autotrophic and heterotrophic plants who live at the same time, at the same location and environmental conditions and interact with each other.

Rhizomatous geophytes: Geophytes that propagate by rhizomes which are fleshy, creeping underground stems.

Synanthropic species: Species that is to some extent associated with man. The life cycles of synanthropic organisms are adapted to conditions created or modified by human activities.

APPENDIX 1: Maps of sampling plots and community types

Maps of 10mX10m Permanent plots and Transect plots

Legend

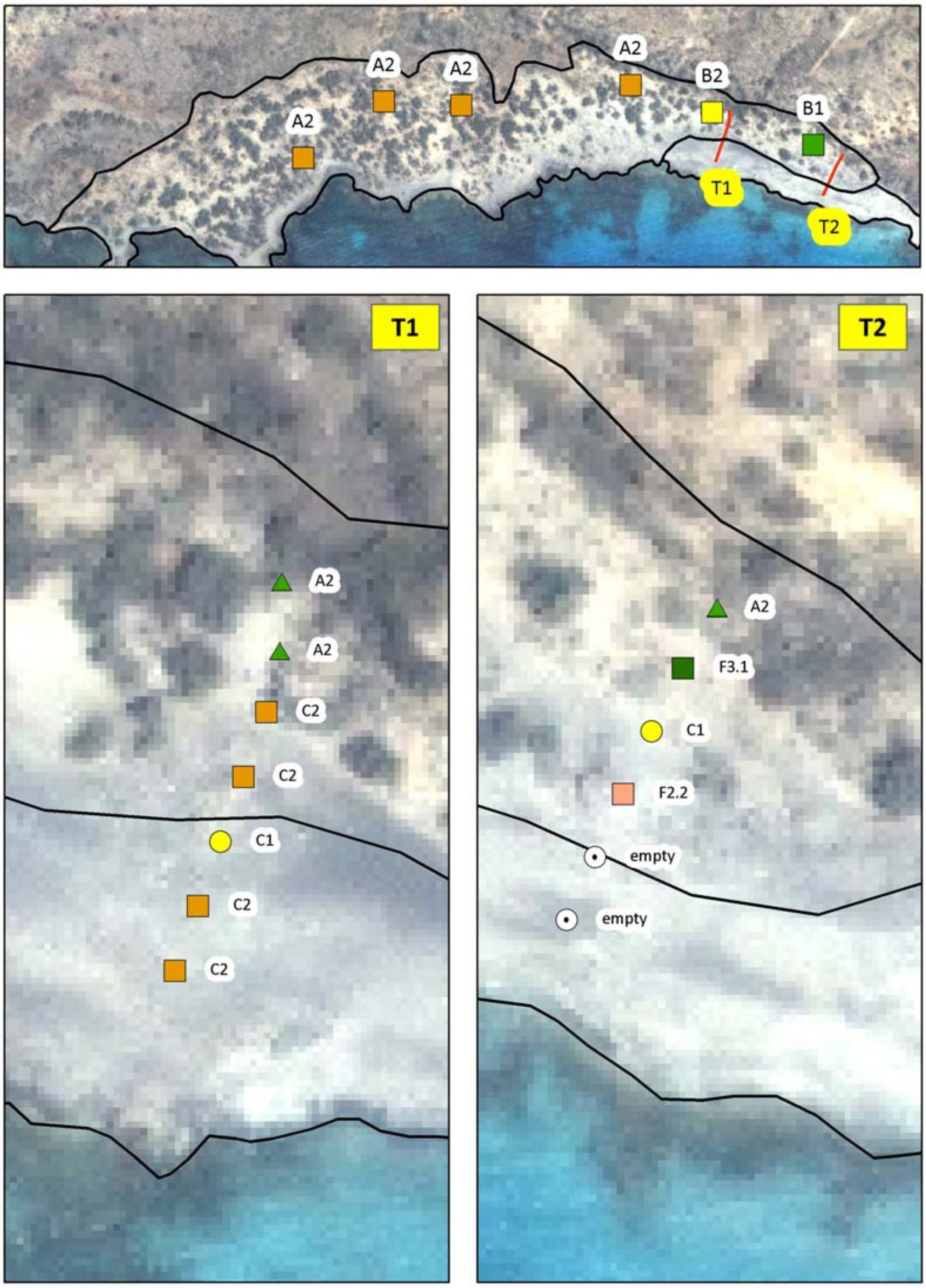
Communities of 10mX10m Permanent plots

- A1: Juniperus phoenicea - Periploca angustifolia
- A2: Malcolmia flexuosa - Nigella stricta
- B1: Silene colorata - Ononis natrix
- B2: Silene succulenta - Cutandia maritima
- B3: Elytrigia juncea - Medicago marina

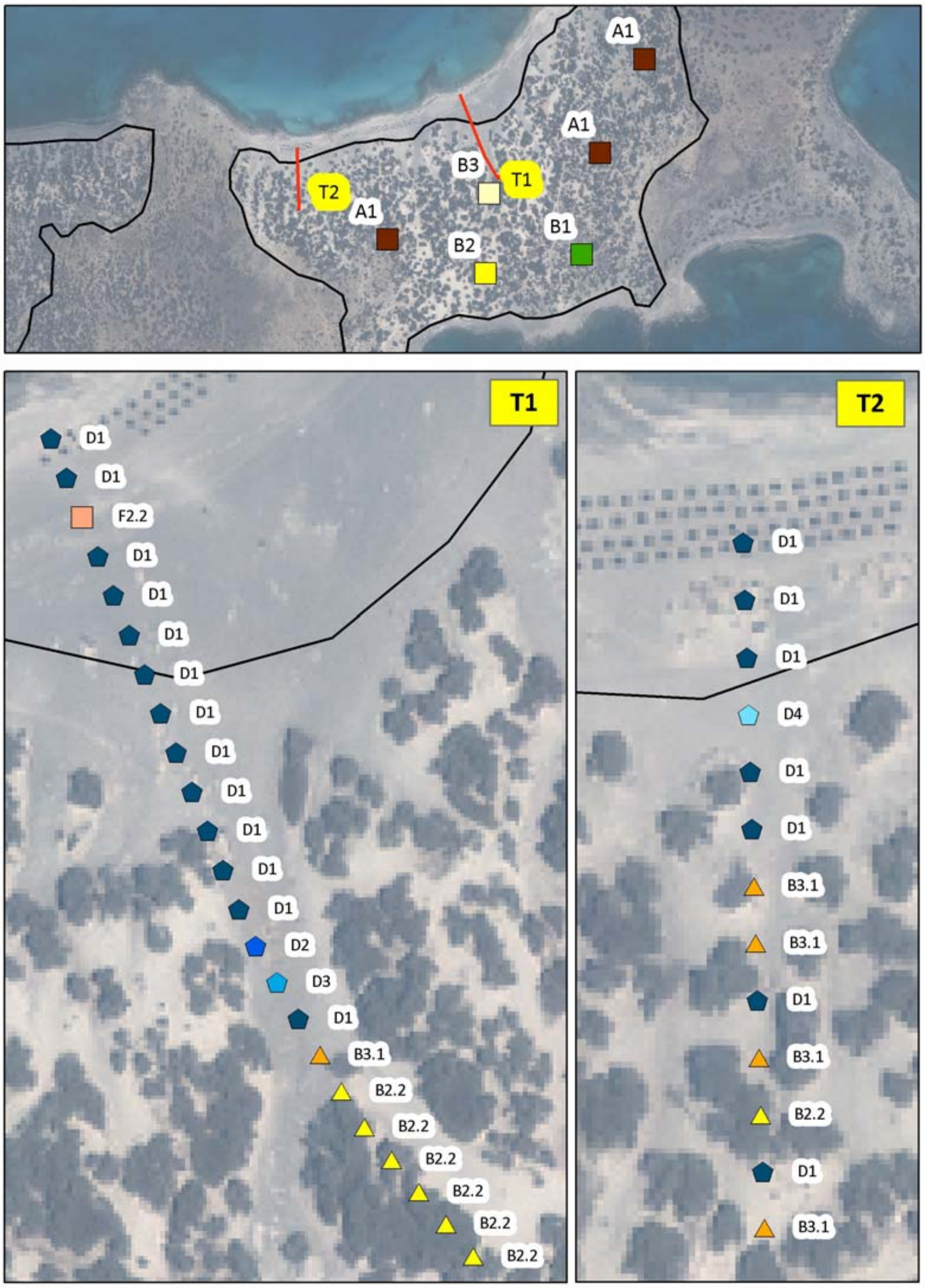
Communities of Transect plots

- A1.1: Dune shrub with Juniperus phoenicea-Asparagus stipularis
- A2: Dune shrub with Juniperus macrocarpa-Nigella stricta and Juniperus phoenicea-Nigella stricta
- B1: Dune shrub with Juniperus macrocarpa characterised by Ononis natrix and/or Coridothymus capitatus or by Limonium elaphonesicum, lacking Silene succulenta and Cutandia maritima and other ammophilous species
- B2: Dune shrub with Juniperus macrocarpa alone or with Cutandia maritima or with Limoniastrum monopetalum
- B2.1: Dune shrub with Juniperus macrocarpa-Limonium elaphonesicum
- B2.2: Dune shrub with Juniperus macrocarpa-Mercurialis annua
- B3.1: High dune with Juniperus macrocarpa-Zygophyllum album
- B3.2: High dune with Juniperus macrocarpa-Pancratium maritimum
- C1: Flat dune with Centaurea pumilio, including also Pancratium maritimum
- C2: Dune shrub with Anthyllis hermaniae-Coridothymus capitatus
- D1: Primary dune with Silene succulenta-Zygophyllum album
- D2: Primary dune with Silene succulenta-Euphorbia paralias
- D3: Dune grassland with Triplachne nitens-Misopates orontium
- D4: Dune slack with Juncus heldreichianus
- F1: Low cover dune vegetation with Limonium elaphonesicum and Pseudorlaya pumila
- F2.1: Foredune or hind dune shrub with Ononis natrix-Coridothymus capitatus (Subcommunity)
- F2.2: Primary dune grassland with Silene succulenta-Pseudorlaya pumila (Subcommunity)
- F3.1: Foredune or hind dune with Ononis natrix-Coridothymus capitatus (Subcommunity)
- F3.2: Primary dune with Silene succulenta-Pseudorlaya pumila (Subcommunity)
- empty plot
- Habitat 2250*
- Transect lines

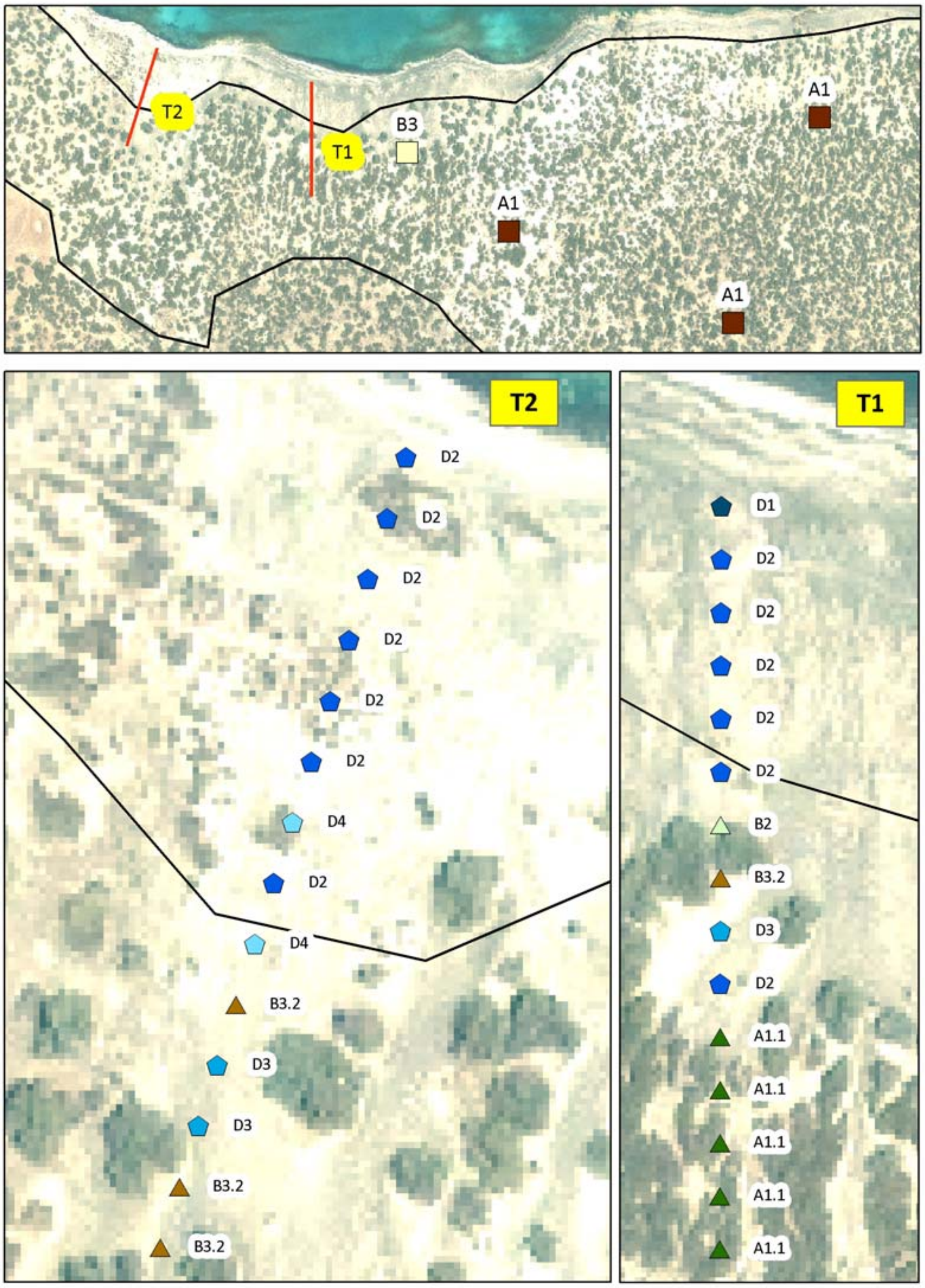
KEDRODASOS - 10mX10m Permanent plots, Transect plots and community type per plot



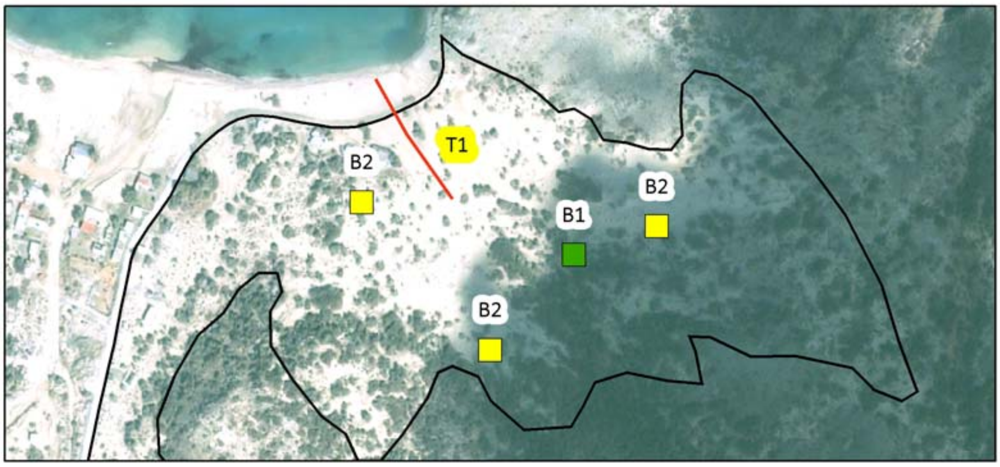
CHRYSI EAST - 10mX10m Permanent plots, Transect plots and community type per plot

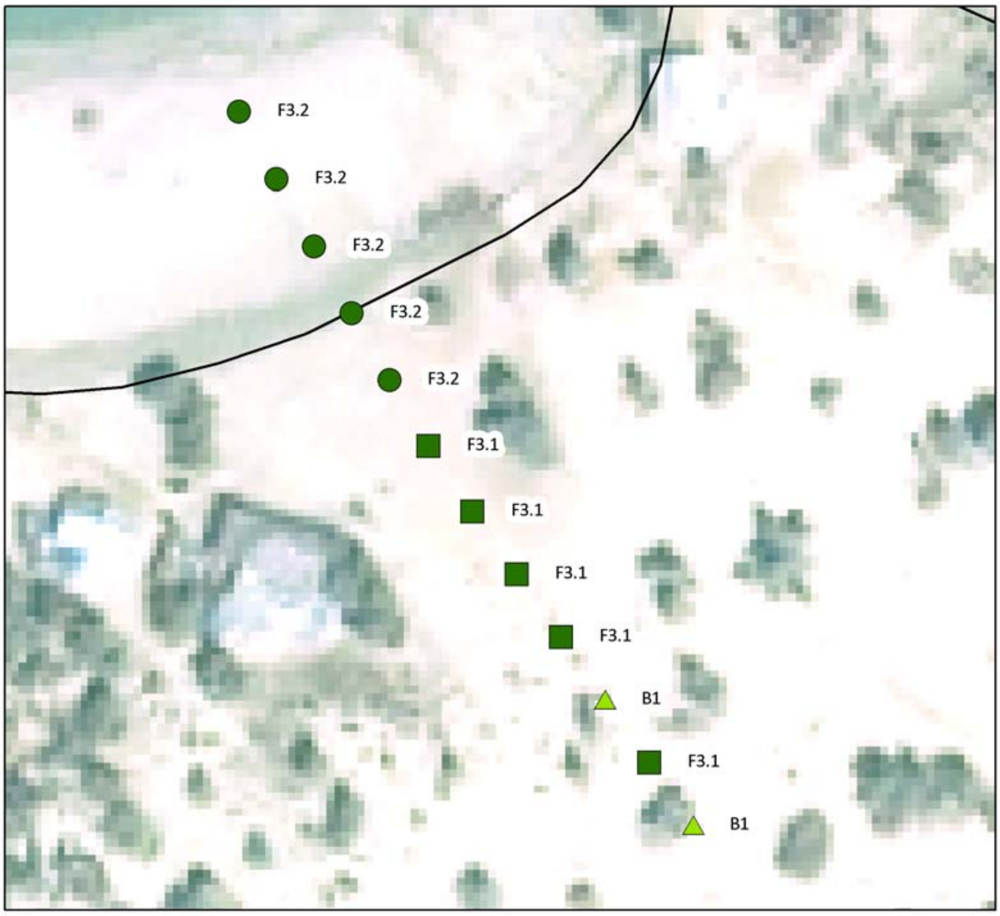


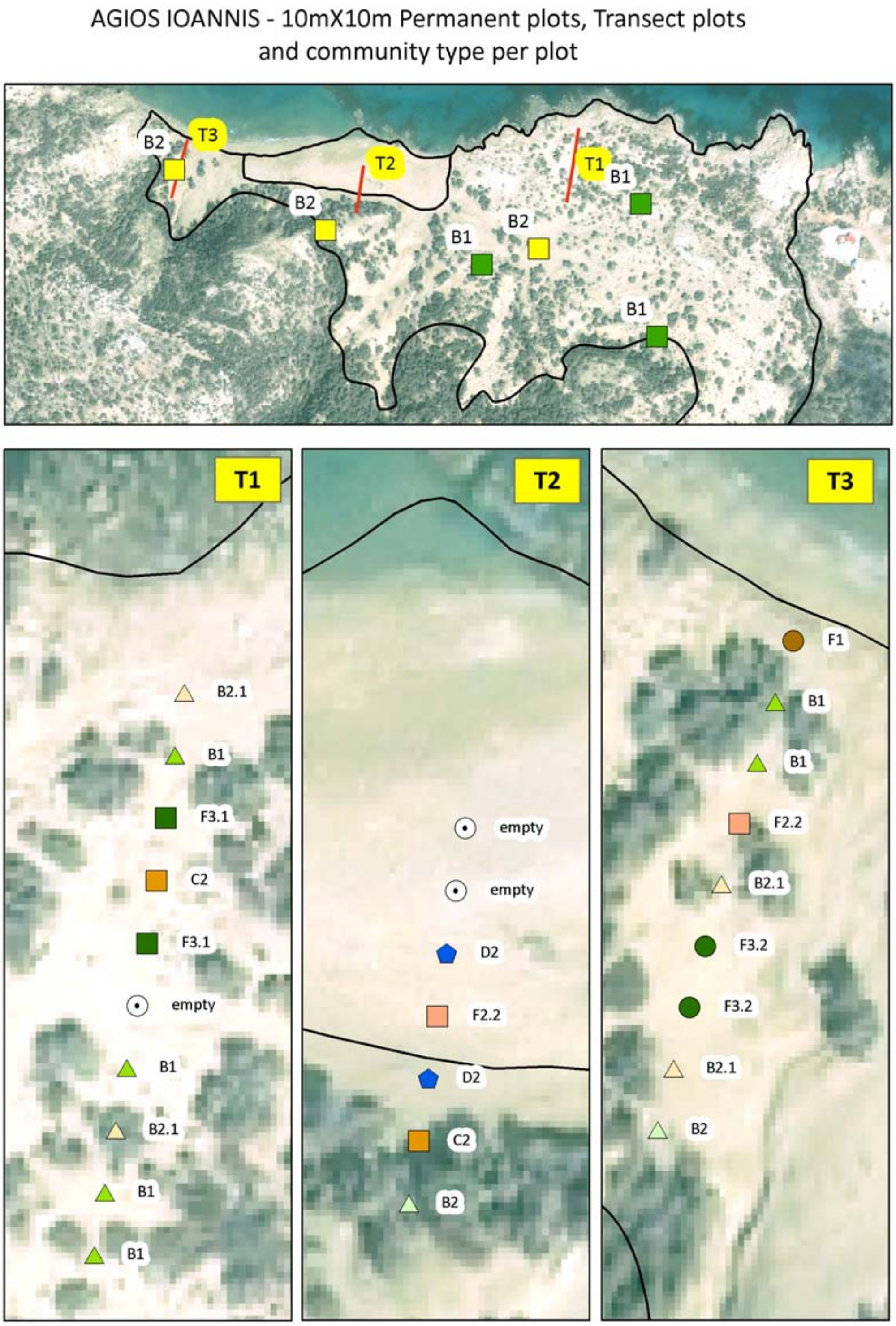
CHRYSI WEST - 10mX10m Permanent plots, Transect plots and community type per plot



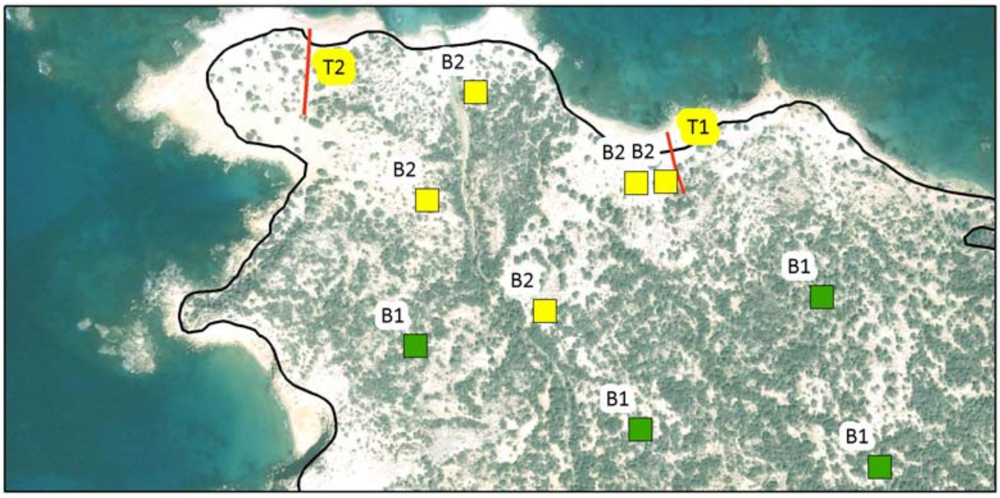
SARAKINIKO - 10mX10m Permanent plots, Transect plots and community type per plot

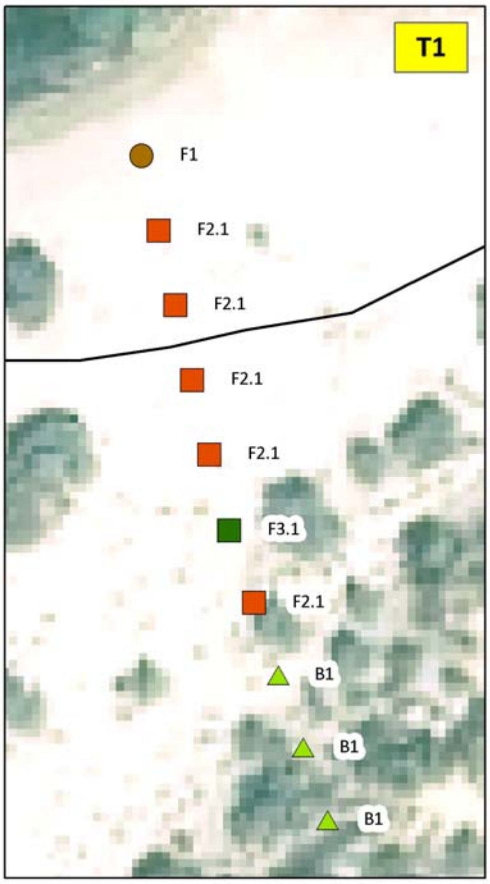


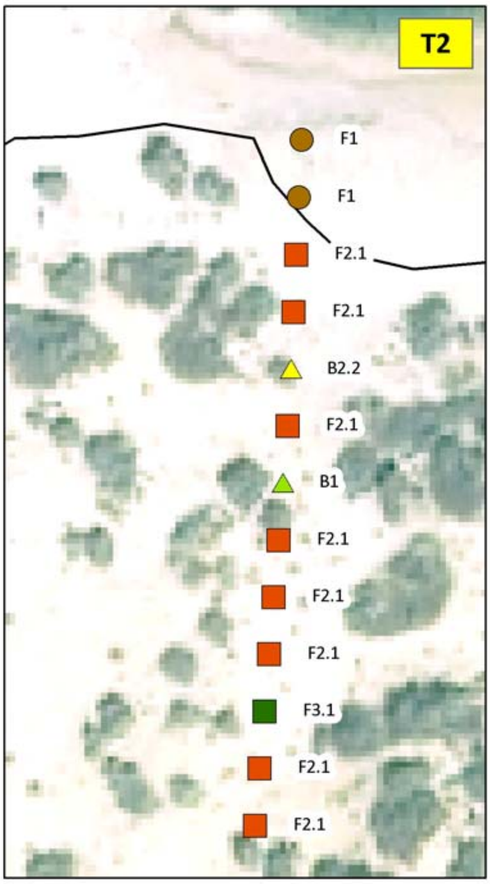



AGIOS IOANNIS - 10mX10m Permanent plots, Transect plots and community type per plot
T3
T2
T1
B2
B2
B2
B1
B1
B1
B2.1
B1
F3.1
C2
F3.1
empty
B1
B2.1
B1
B1
empty
empty
D2
F2.2
D2
C2
B2
F1
B1
B1
F2.2
B2.1
F3.2
F3.2
B2.1
B2

LAVRAKAS - 10mX10m Permanent plots, Transect plots and community type per plot







FALASARNA - 10mX10m Permanent plots, and community type per plot

APPENDIX 2: Flora of all study areas with their life forms and functional attributes

Taxon	Family	endemic	threatened	protected	Ellenberg Numbers							Functional attributes					Sites (No of plots in habitat 2250)						
					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Aetheorhiza bulbosa subsp. microcephala	aste				5	x	5#	x	x	5	1	Gbulb											
Aira elegantissima subsp. elegantissima	poac				7	7°	3#	3	6	2	0	Tcaesp			+				3				
Allium rubrovittatum	lili				9	x	6#	2	8	2	x	Gbulb							2				
Anagallis arvensis	prim				6	x	4°	x	8	5	1	Trept							4				
Anthyllis hermanniae	faba				8	8°	5#	3	8	3	1	Chfrut							6		2	2	
Arenaria leptoclados	cary				8	7°	x	3	8	4	0	Tscap					2	1	4			1	
Asparagus stipularis	lili				8	8	7	1	8	3	2	Chfrut					3	6					
Asperula rigida	rubi	+			x	x	5#	3°	8#	2	0	Chfrut											1
Asphodelus ramosus	lili				8	x	5	3°	7	6	1	Grhiz								1			
Asterolinon linum-stellatum	prim				7	x	5	4°	x	2	1	Tscap					1	1	2				
Atractylis cancelata	aste				8	8°	5	2	8#	5	1	Tscap							2				
Bellium minutum	aste				8	8	5#	2	8	5	3	Tscap						2					
Biscutella didyma	bras				8	7°	5	3	7	5	1	Tscap	+						1			1	
Brachypodium distachyon (=Trachynia distachya)	poac				6	8°	5	x	8	x	1	Tcaesp					2		6				1
Brassica tournefortii	bras				9	9	5	3	8	5	3	Tscap			+		1						
Briza maxima	poac				6	8°	5	x	7	3	0	Tcaesp							1				
Bromus fasciculatus	poac				8	8°	5	2°	8	4	2	Tcaesp					3	1	5		1		
Bromus intermedius	poac				8	x	5	x	8	6	1	Tcaesp							2				
Bromus madritensis	poac				7	x	6	4°	7	5	0	Tcaesp							1				
Bromus sterilis	poac				7	x	6	4°	7	5	0	Tcaesp							1				
Bupleurum gracile	apia				7	7	5#	2	8	3	0	Tscap			+				1				
Bupleurum semicompositum	apia				8	9	5	5	9#	4	2	Tscap					4	2				1	
Cakile maritima	bras				8	8	x	5	9#	8	4	Tscap					14	1				2	2
Calicotome villosa	faba				7	x	5#	3	7	2	0	Pcaesp				+				1			
Campanula erinus	camp				8	7°	5	2	8	5	1	Tscap					3	1	5				
Carlina sp.	aste											Hbienn							1				
Carrichtera annua	bras				9	9	6	1	9	4	1	Tscap		+		+	1						

Taxon	Family	endemic	threatened	protected	Ellenberg Numbers							Functional attributes					Sites (No of plots in habitat 2250)						
					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Carthamus sp.	aste											Tscap							5				
Catapodium rigidum	poac				7	x	4°	3	7	2	0	Tcaesp							2				3
Centaurea aegialophila	aste		+	+	9	9	7#	3	9#	5	3	Hros						1					
Centaurea pumilio	aste		+	+	9	9	6	3	9#	5	3	Hros								2			
Centaurium tenuiflorum	gent				8	8	5	7	8	4	x	Tscap					2	4	1				
Centranthus calcitrapae	vale				6	x	5	4	8	2	0	Tscap							4				
Ceratonia siliqua	faba				?	8	5#	3	8	4	0	Pcaesp							7				
Chenopodium murale	chen				7	8°	4°	4	8	9	1	Tscap	+						3				
Cistus creticus subsp. creticus	cist				7	7°	5	3	7	2	1	Chfrut	+									5	1
Cistus parviflorus	cist				8	8°	6#	2	8	x	1	Chfrut									1	2	
Clypeola jonthlaspi	bras				8	x	5	3	8	6	0	Tscap							1				
Colchicum cousturieri	lili	+	+	+	9	9	6#	0	9#	3	3	Gbulb						1					
Coridothymus capitatus	lami				8	x	5	3	8	3	1	Chfrut					2	1	9	2	7	10	4
Coronilla scorpioides	faba				7	7°	5	3	8#	5	1	Tscap					1						
Crepis multiflora	aste				6	8	5#	x	9#	6	2	Tscap		+			2	2	6	1	7	9	1
Crucianella latifolia	rubi				6	8°	6°	3	8	2	1	Tscap							1				
Cuscuta palaestina	conv				7	8°	5	3	8	?	1	Tpar				+			6	2			
Cutandia maritima	poac				9	8	6	2	9#	5	3	Tcaesp				+	5				7	2	3
Daucus guttatus	apia				8	8°	6	4	8	6	1	Tscap							7				
Echium arenarium	bora				9	8	5	3	8	8	1	Hbienn			+		4		1	1			
Elytrigia juncea	poac				8	8	5	3	8	5	5	Grhiz			+		6	1		2			
Erica manipuliflora	eric				7	x	5#	3	7	2	1	Chfrut					2				1	2	1
Erodium cicutarium	gera				7	x	x	4	x	7	1	Tcaesp							6		5	2	2
Erodium laciniatum	gera				8	8°	6	3	8	8	3	Tscap					11	9	2	1		3	
Erodium malacoides	gera				8	8°	5	4	8	8	0	Tscap			+				3	1			
Eryngium maritimum	apia				8	8	3	4	8	7	3	Grhiz			+					2			
Euphorbia paralias	euph				9	8	4	4	8	7	3	Chfrut	+		+	+	1			2			

Taxon	Family	endemic	threatened	protected	Ellenberg Numbers							Functional attributes					Sites (No of plots in habitat 2250)						
					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Euphorbia peplus	euph				6	x	3#	4	x	7	1	Tscap					4	3	4		1	5	
Fagonia cretica	zygo				9	9	8	1	9#	7	2	Chsuffr					3						
Filago aegaea subsp. aegaea	aste				9	8°	5#	1	8	3	1	Tscap					1	2					
Filago gallica	aste				8	7°	2°	2	7	x	0	Tscap							1				
Filago pyramidata	aste				8	8	4	3	8	6	0	Tscap										1	
Fumana thymifolia	cist				9	7°	5	2	8	x	1	Chsuffr			+		1	2				3	
Galium graecum	rubi				7.5	8	5.5 #	1.5	8	x	1	Chsuffr							1				
Galium murale	rubi				7	x	x	x	7	4	0	Tscap					2		2				
Galium setaceum	rubi				8	8°	4°	4°	8	7	0	Tscap							1				
Gastridium phleoides	poac				8	7°	5	4	x	4	1	Tcaesp											3
Genista acanthoclada	faba				8	7°	5	3	x	2	1	Chfrut								1			
Glaucium flavum	papa				8	8	5	5°	8	6	2	Hscap								1			
Globularia alypum	glob				8	9	5	1	8	3	0	Chfrut									2	1	1
Hedypnois cretica	aste				7	8°	5	4°	8	7	1	Tscap					2		7	2	5	6	4
Hedysarum spinosissimum	faba				8	8	5	2	9#	7	2	Tscap										1	
Helianthemum stipulatum	cist		+	+	9	9	8	0	9#	6	2	Chfrut					2	2					
Helichrysum conglobatum	aste				8	8°	5	3	8	x	1	Chsuffr					3	2				1	
Herniaria hirsuta	cary				8	7	7	5	7	7	0	Hcaesp	+						2				
Hordeum sp.	junc												+						1				
Hyoseris lucida	aste				8	8	4	4	9#	8	3	Hros	+							1			
Hypochaeris achyrophorus	aste				7	7°	5	3	x	4	1	Tscap	+					2	1				
Juncus heldreichianus	junc				7	7°	5#	8°	8	6	x	Hcaesp	+										
Juniperus macrocarpa	cupr				9( )	9	6	2	8	3	3	Pcaesp					16	9	8	2	18	12	4
Juniperus macrocarpa s	cupr				9( )	9	6	2	8	3	3						2						
Juniperus phoenicea	cupr				8( )	8	5	2	8	x	x	Pcaesp					4	9	6		3	2	1
Lagoecia cuminoides	apia				7	x	6°	4	x	5	1	Tscap							2				
Lagurus ovatus	poac				8	7°	5	x	8	6	1	Tcaesp							7		2	1	2

Taxon	Family	endemic	threatened	protected	Ellenberg Numbers							Functional attributes					Sites (No of plots in habitat 2250)						
					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Lamyropsis cynaroides	aste				6	7	5#	4	7	6	1	Hscap								1			
Limoniastrum monopetalum	plum				9	8	7	x	9#	6	9	Chfrut						1					
Limonium echioides	plum				8	9	5	1	8	7	3	Tros		+				1	3		2	6	
Limonium elaphonisicum	plum	+			8	8	4#	0	8	4	?	Chsuffr		+							1	1	
Limonium graecum subsp. graecum	plum				8	9	5#	x	9#	7	6	Chsuffr						8		1			
Limonium sp.	plum																1						
Limonium virgatum	plum				8	8	5	x	8	6	6	Chsuffr	+				1						
Linum strictum	lina				7	8°	6°	x	8	5	1	Tscap					1		4		1	1	
Lolium rigidum subsp. rigidum	poac				7	x	4°	5	8	8	1	Tcaesp			+					1			
Lotus angustissimus	faba				7	x	4°	7	7	x	1	Tscap									1		
Lotus halophilus	faba				8	9	6	2	9#	6	3	Tscap					10	11	8	2	7	9	4
Lycium schweinfurthii	sola				9	9	7	1	8	8	3	Pcaesp						3					
Malcolmia flexuosa	bras				7	8	5#	3	8	7	4	Tscap							7				
Malva parviflora	malv				7	8°	4°	5	8	8	0	Tscap		+						1			
Mandragora autumnalis	sola				8	7°	5	4	8	8	1	Hros							3				
Medicago coronata	faba				7	8°	6	2	8	4	1	Tscap							1				
Medicago littoralis	faba				8	8	5	2°	8	7	2	Tscap					2	2	6	1	2	4	3
Medicago marina	faba				9	8	4	4	8	8	3	Chrept					1			2			
Mercurialis annua	euph				x	8	4°	x	8	8	1	Tscap					8						
Mesembryanthemum nodiflorum	aizo				9	8	5	1	9#	7	9	Tscap						1					
Minuartia mediterraneae	cary				8	8°	4	3	8	7	1	Tscap							1				
Misopates orontium	scro				8	7°	3	4	8	5	1	Tscap					1	3	1				
Muscari spreitzenhoferi	lili	+			7	x	5#	3°	8	4	1	Gbulb					4	3	4				
Nigella stricta	ranu	+	+	+	8	8	5#	1	8	6	3	Tscap							9				
Onobrychis caput-galli	faba				7	7°	6	4	8	6	1	Tscap							1				
Ononis natrix subsp. hispanica	faba				8	8	6	4	8	7	2	Chsuffr									4	12	1
Ononis reclinata	faba				7	8°	x	2	8	5	1	Tscap					6	7	1			3	1

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					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Onopordum sp.	aste																			1			
Orobanche pubescens	orob				6	7	5	5	x	4	1	Tpar							1				
Orobanche ramosa	orob				7	8°	x	3°	x	7	1	Tpar					2		5				
Pancratium maritimum	amay				8	8	4°	4	9#	5	3	Gbulb					4	11		2			
Papaver purpureomarginatum	papa				7	x	5#	4	8	7	1	Tscap							1				
Parapholis incurva	poac				8	8	4°	6°	9#	6	7	Tcaesp					3				7		
Parietaria cretica	urti				x	8°	5#	5	9#	7	1	Hscap							4				
Paronychia macrosepala	cary				8	x	5#	x	8	5	x	Hcaesp					1	3					
Periploca angustifolia	ascl		+		9	9#	8	0	8	5	2	Pcaesp					3	7			6		
Phagnalon graecum	aste				8	8°	5	2	8#	x	1	Chsuffr					5	12	6		4	7	1
Phleum crypsoides	poac				9	9	5	2	9#	6	8	Tcaesp					1	2				2	4
Pinus brutia	pina				7( )	7°	5#	3	7	2	1	Pscap					1				2	4	1
Piptatherum miliaceum	poac				7	8°	5	4°	8	5	1	Hcaesp					1	2					
Pistacia lentiscus	anac				7( )	8	5	x	8	x	x	Pcaesp					6	7	9	2	5	5	4
Plantago albicans	plan				8	9	5	2	8	4	2	Chsuffr					2	4					
Plantago bellardii subsp. bellardii	plan				7	8°	6	3	8	4	1	Tros							2	2			
Plantago cretica	plan				7	7°	6	4	8	5	0	Tros					1						
Plantago lagopus	plan				7	8°	5	4	8	6	1	Tros							3				
Plantago squarrosa	plan				9	9	5	1	9#	6	3	Tscap							8		11	7	4
Plantago weldenii	plan				8	7°	5	5°	8	6	2	Tros					3	2	1				
Polycarpon tetraphyllum	cary				8	8°	4°	4°	8	5	1	Tscap					1	2	3			2	1
Prasium majus	lami				x	8	5	3	x	5	1	Chfrut					7	7		2	6	5	1
Pseudorlaya pumila	apia				9	8	5	3	9#	5	3	Tscap					11	1	8	2	9	8	4
Psilurus incurvus	poac				7	7°	6°	x	x	3	1	Tcaesp							1				
Reichardia picroides	aste				7	8°	5	x	8	6	x	Hscap								1			
Rostraria cristata	poac				8	x	5	4°	8	7	x	Tcaesp							1			2	1
Rumex bucephalophorus subsp. bucephalophorus	polo				8	7°	4	3	8	6	1	Tscap					1		4		2	7	

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					L	T	K	F	R	N	S	Life Form	Pubescent	Succulent	Nitrogen fixer	Sand fixer	Chrysi-Anatoliko	Chrysi-Anatoliko	Elafonisi	Falasarna	Gavdos-Agios Ioannis	Gavdos-	Gavdos-Sarakiniko
Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Salsola kali	chen				8	8	x	4	8	8	4	Tscap					3	1				1	
Salvia viridis	lami				8	8°	5	2	9	6	1	Tscap							2				
Satureja nervosa	lami				8	7°	5	3°	8	4	1	Chsuffr							1				
Satureja thymbra	lami				7	x	5#	3	7	2	1	Chfrut										2	2
Senecio vulgaris	aste				7	x	4°	4	x	7	1	Tscap					1		4			2	
Silene ammophila subsp. ammophila	cary				8	9	6#	1	9#	7	3	Tscap					2	1					
Silene colorata	cary				8	8	5	4	8	7	2	Tscap								2	8	7	4
Silene nocturna	cary				8	8	5	2	9#	7	1	Tscap							1				
Silene sedoides	cary				8	8	5	1	9#	7	7	Tscap						5		1	1		
Silene sp.	cary																		1				
Silene succulenta	cary		+	+	9	9#	8°	1	9#	6	5	Hscap					16	5			12	5	3
Sonchus asper subsp. asper	aste				7	8	4°	5	7	7	1	Tscap								2			
Sonchus oleraceus	aste				7	7°	x	5°	8	8	1	Hbienn					7	4	3		4	5	2
Sporobolus pungens	poac				9	8	5	6	8	6	5	Grhiz								2			
Stipa capensis	poac				9	8	5	1	9#	7	1	Tcaesp							1				
Teucrium alpestre	lami	+			8	x	5#	3°	7	x	1	Chsuffr					1	1	3				
Teucrium brevifolium	lami				8	9	5#	2	8	x	1	Chfrut					3	3					
Torilis nodosa	apia				7	x	3°	5	7	7	1	Tscap						1	1				
Trifolium angustifolium	faba				7	8°	5	6	7	5	1	Tscap							1				
Trifolium campestre	faba				7	x	4	4°	x	x	1	Tscap						1	4			1	
Trifolium scabrum	faba				7	x	5	2	8	5	1	Tscap						1	1		3	1	1
Triplachne nitens	poac				8	9	5	1	8	6	2	Tcaesp					16	11	4	2	7	9	
Urginea maritima	lili				7	8°	5	2°	8	x	1	Gbulb							6		1	5	2
Urospermum picroides	aste				7	8°	5	4°	8	7	1	Tscap					2		5		2	1	2
Urtica pilulifera	urti				6	8	5	5	8	7	0	Tscap							1				
Valantia hispida	rubi				7	x	5	4°	8	x	2	Tscap					13	10	8		3	2	1
Valantia muralis	rubi				7	x	5	4°	x	x	x	Tscap					1				1		

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Acanthus spinosus	acan				7	8°	5	4	x	7	0	Hscap							1				
Verbascum spinosum	scro	+			8	x	5#	4	7	6	1	Chfrut							3				
Vulpia fasciculata	poac				8	8	4	3	8	6	2	Tcaesp					11	4	9	1	8	6	4
Zygophyllum album	zygo		+	+	9	9	8	0	9#	7	6	Chsuffr					6						