Millipedes. Millipedes, like many other terrestrial arthropods, decrease in numbers seawards. However, a few species have adapted to beach life. One of the most typical is the nemasomatid juloid *Thalassisobates litoralis*, found in the western Mediterranean and Atlantic areas. Once frequent on the Tyrrhenian and Adriatic coasts, Sicily and Sardinia, its numbers are now decreasing.
The species is associated with intertidal environments, where it is found in *Zostera* and other seagrasses deposits, although it prefers rocky, pebbly beaches or those with alternating sand and calcareous pebbles. In Sicily, in eulittoral terraces, there is another julid, *Dolichoiulus tongiorgii*, which is widely distributed in the western Mediterranean and associated with stranded wooden material (tree-trunks, remains of rushes, canes, etc.). Other, more euryecious species which may be found under stranded debris are the polyxenid *Polyxenus lapidicola* (a Mediterranean species typical of southern Italy), the lophoproctid *Lophoproctus jeanneli* (= *L. litoralis*), a western Mediterranean species found in southern Italy, and the polydesmoid *Stosatea italica* (an Atlantic-Mediterranean species typically found throughout Italy).

Molluscs. Although molluscs are common on beach and terrestrial ecosystems, the narrow madolittoral terrace is not particularly compatible with them, especially because sea molluscs find it hard to penetrate inland and terrestrial ones cannot even touch sea water. Among the few which have adapted to life on sandy beaches is a small ellobiidof the genus *Myosotella*, *M. myosotis* (also called *Alexia myosotis* or *Ovatella myosotis*), which often lives with sand fleas in stranded debris on damp beaches of sandy-gravelly supralittorals.

■ Communities of embryo and consolidated dunes, dune and heathland maquis, and fossil dunes

Crustaceans. All crustaceans, even terrestrial ones, which need damp substrates, natural shelters and large quantities of organic matter, find it very difficult to survive in these dune habitats with dry substrates containing little or no humus. Embryo and consolidated dunes, except for possible dune heathland woodland and night excursions of eulittoral species, are colonized only by a few isopods, which live in grasses and shrubs, where humidity and vegetal debris are suitable for the survival of various sea-loving species, such as *Porcellio lamellatus, Armadillidium etruriae, A. silvestrii, A. argentarium*, a few *Philoscia*, and others.

Beetles. Exposed dry beaches contain the first terrestrial plants of supralittoral belts. There are therefore many indirectly dune-loving beetles, which are more or less strictly associated with these pioneering, specialized plants, together with detrivorous, saprophagous animals and predators, which also live in madolittoral belts. Numbers of phytophagous species increase greatly on dunes, which are also populated by organisms usually found in Mediterranean maquis and garrigue.
● **Ground beetles**. Ground predators, which are adapted to moderately damp substrates, find it difficult to live in sandy, dry, open dunes or dune heathland.

Pimelia bipunctata

Tentyria grossa

However, together with the already described *Lophyridia littoralis*, which often lives in good-quality dunes, other ground beetles may be considered typical of embryo and consolidated dunes. Another interesting tiger beetle is the typically psammophilous *Lophyra flexuosa*, which lives in Atlantic and western Mediterranean areas (as far as Egypt, Israel and Syria), in sandy environments of dunes and heathland, far from the water, even in inland paleo-dunes (e.g., Is Pabillonis in Sardinia). In Italy, it is found only in Sicily and Sardinia. The most typical and widely distributed component of coastal dunes in the western Mediterranean is the enormous scaritine *Scarites buparius*, a night predator of various shore invertebrates, but also the smaller *Masoreus aegyptiacus*, which lives in the southern Mediterranean, and *Cryptophonus melancholicus*, distributed in Europe and the Mediterranean. In the past, *Scarites buparius* lived in almost all sandy shores in Italy and its islands, except for the middle and high Adriatic, but now its numbers have plummeted owing to the destruction or reduction of dune environments. Scaritines are mainly nocturnal animals: during the day, they hide in the vegetation or in burrows dug with their strong front legs and large scythe-like jaws. During the night, *Scarites buparius* preys on large numbers of small, sand-loving invertebrates, like sand fleas, darkling beetles - *Pimelia* and *Tentyria* - the larvae of owlet moths and land molluscs.
● **Rove beetles**. As they are associated with sufficiently damp substrates, a very few live in prohibitive environments like dunes. There are only a few euryecious and xero-thermophilous species.
● **Click beetles**. The only click beetle of Italian dunes, apart form the already-mentioned *Isidus moreli*, is *Cardiophorus exaratus*, found in the western Mediterranean. On the coasts of central-southern Italy, it may live under dune grasses.
● **Sap beetles**. Sap beetles, cybocephalids and kateretids (pollen beetles) are small beetle families, 200 species of which live in Italy. Embryo dunes and ammophila meadows contain easily adaptable species, such as the common *Meligethes aeneus* - often found on sea-rocket flowers (*Cakile maritima*) - or its congeners *M. carinulatus, M. erichsoni* and *M. nigrescens*, which live in dunes colonized by various leguminous plants of the genus *Lotus*. Far more

important is the newly-discovered dune "specialists" of the western Mediterranean, belonging to the small *Meligethes, M.* cfr. *longulus* which is exclusive to dunes and monolithic rocks of good environmental quality and associated with crucifer flowers of the genus *Matthiola*. Among specialists of psammo-halobious leguminous plants, are two western Mediterranean species which in Italy are only found in western Sardinia, *Meligethes varicollis* (associated with *Lotus* spp.) and *M. opacus* (associated with *Ononis* spp.).
The Tyrrhenian coasts of central-southern Italy and its islands contain many other *Meligethes* and pollen beetles which are typical of shrub-maquis and garrigue, but may also be found in consolidated dunes and dune heathland, such as the western Mediterranean *Meligethes fuscus* (associated with *Cistus* spp.), *M. grenieri* (rare, associated with *Rosmarinus officinalis*, found in Sardinia and coasts of the Maremma), *M. nigritus* (associated with *Lavandula stoechas*), *M. lindbergi* (associated with *Teucrium flavum*), *Meligethinus pallidulus* (associated with the male spathes of dwarf fan palms of rocky coasts, but also found on dunes, e.g., southern Sicily). There are also many small species of the genus *Cybocephalus* (round about 1 mm long), which live as specialized predators of armour-scaled homopterans on various maquis shrubs and dune heathland, particularly on tamarisks.

● **Shining flower beetles**. These are a family of small anthophagous or mycophagous beetles. One of the few species which are frequently found on dunes is *Olibrus affinis*, a European-Mediterranean species associated with various small xerophilous composites (*Tragopogon, Hypocheris*).

● **False tiger beetles and blister beetles**. Among the most typical false tiger beetles is *Stenostoma rostratum* (= *S. coeruleum*), widespread in the Atlantic and Mediterranean and associated with the thorny flowers of the umbellifers *Eryngium maritimum* and *Echinophora spinosa*. Other, less specialized members of the same family, such as *Nacerda melanura* and a few *Oedemera* (e.g., the common *O. flavipes* and *O. barbara*), live on flowers of many dune plants, especially composites.
In embryo dunes and dune heathland. *Stenostoma* are good indicators of the environmental quality of wandering dunes and tend to disappear where disturbance is stronger.
Among blister beetles, only one species is typical of dunes and dune heathland (although sometimes found in subcoastal maquis and garrigue), the

Zonitis bellieri

rare *Zonitis bellieri*, which usually lives on inflorescences of ligulate composites in North Africa, western Anatolia and Sicilian coasts.

● **Darkling beetles**. As we have previously seen, a few darkling beetles (*Phaleria* spp., *Xanthomus* spp.) are typical of madolittoral communities of damp beaches. Some of them, which may often wander as far as waterlines, like the already mentioned *Tentyria* and *Pimelia*, are typical of foredune agropyretum, dunes and sandy fossil dunes, such as *Halammobia pellucida, Pachychila* (*P. frioli, P. germari, P. servillei*) and, again, *Xanthomus pallidus* and *X. pellucidus*, a few *Erodius* (e.g., *E. siculus*, *E. audouinii*), *Stenosis* (*S. intermedia*), *Trachyscelis aphodioides*, *Pseudoseriscius helvolus, P. normandi, Cataphronetis crenata, Gonocephalum lefranci, G. setulosum, Gunarus parvulus, Nalassus aemulus,* and many other genera and species.
Darkling beetles, some of which are diurnal and others nocturnal (generally active in spring and autumn), colonize open areas of dunes. From the naturalistic and biogeographical points of view, the most important are endemic Italian species, such as the rare *Psammoardoinellus sardiniensis*, a psammophilous species which was discovered only a few years ago in the sandy dunes of central-western Sardinia, *Stenohelops carlofortinus*, of southern Sardinia, and many endemic subspecies which are distributed in the Mediterranean. Sicilian and Sardinian coasts also feature the large sand-loving species *Pimelia grossa*, typical of the Maghreb.

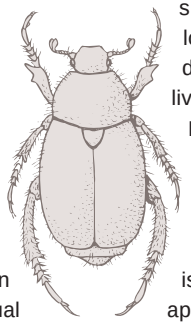
● **Scarabs.** Agropyretum, embryo dunes and sand reed meadows contain various scarabs, some of which are extremely important from the naturalistic and conservationist points of view. Among dung beetles, there are a few psammophilous, detrivorous, sea-loving and root-eating species which are usually found on the stalks of pioneering vegetation throughout the Mediterranean, such as the small, convex *Brindalus porcicollis*, *Psammodius basalis, P. laevipennis*, and a few psammophilous *Rhyssemus*, which usually live on sandy shores of lakes and rivers. Some of these are also typical of sandy sea shores, like *Rhyssemus plicatus* and *R. sulcatus*, which are found on the coasts of central-southern Italy.
Among the most interesting species is the curious *Psammodius nocturnus*, an eastern Mediterranean species which colonizes the dunes of best environmental quality of the Adriatic, from Friuli to Apulia, sometimes reaching areas in southern Sicily near Gela. This micropterous and microphtalmic species, i.e., unable to fly, almost blind, depigmented and strictly dune-loving, burrows deeper in sand than most Mediterranean psammophilous alies and may be considered one of the most typical and best adapted "specialists" of sandy dune environments in Italy and throughout the Mediterranean.
Other coprophagous dung beetles (feeding on excrement of herbivorous and omnivorous mammals) occasionally live in sand dunes, are widely distributed, and have a great ecological value, such as various *Aphodius*.
It is worth mentioning the rare and endemic *Heptaulacus rasettii*, coprophagous and psammophilous, which lives in only a few Tuscan fossil dunes (Tombolo di Pisa and San Rossore) and is one of the Italian insect species at highest risk of extinction.
Among "dor" beetles, typically

coprophagous and associated with excrement of herbivorous mammals, is *Thorectes marginatus*, distributed in the Sicilian-Maghrebian area. In the past, this large beetle colonized several Sicilian coastal dunes, but today it may only be found in a few beaches of southern Sicily, and its numbers are clearly falling owing to the disturbance of its habitats. It feeds on the excrement of wild rabbits and sheep.
The extremely rare and localized *Ceratophyus rossii*, endemic to the Tyrrhenian coasts, is even more important and risks extinction.
It may certainly be found in a few fossil dunes covered with sub-coastal woodland and consolidated dunes in Tuscany between Tombolo di Pisa and the Oasis of Burano near Grosseto. This species feeds on horse excrement, under which it burrows deep, vertical tunnels where food is stored to feed its larvae.

Among true scarabs of sandy beaches, there are a few large or even enormous members of the genus *Scarabaeus,* known since Egyptian times for the typical way in which they roll small balls of dung of large herbivorous mammals. This material is used to lay eggs and develop larvae. The most typical is the common *S. semipunctatus*, found in the western Mediterranean. This is a strict dune-lover, distributed on sandy beaches in Italy and its islands.
Another scarab is the now rare and larger *S. sacer*, typical of the Mediterranean-Sindic regions, which is gradually disappearing in Italy due to disturbance in the sandy beach biotopes with which it is closely associated, particularly wide, sandy-silty dune heathland where animals graze. In the 1970s and 1980s, *Scarabaeus sacer* started disappearing from Italy - the Tyrrhenian coasts of

Sacrabeus semipunctatus

Tuscany and Calabria, Sicily and Sardinia. Today its large populations may only be found in southern Italy and its islands.
Among cockchafers, many species are associated with sandy dune environments. The most important is the large and beautiful *Polyphylla ragusai*, a rare species endemic to Sicily, where it may be found in two distinct subspecies which live in north-western and south-eastern Sicilian coasts respectively, especially in dunes and heathland. They are a summer species of root-eating larvae; the males fly at dusk in search of the females, which shelter under dune vegetation. The numbers of this species are gradually falling, and it may be considered extinct in the northern Sicilian coasts, due to its continual disturbance. *Anoxia orientalis* and *A. scutellaris* are similar to *Polyphylla ragusai*, with which they also share the same ecology and habits. *A. orientalis*, distributed in the eastern Mediterranean, may be found on Sicilian and Calabrian coasts. *A. scutellaris* lives throughout Italy and Sardinia and features two endemic species, in the northern and southern Sicilian coasts respectively. *Haplidia massai*, endemic to Sicily, may only be found in dune heathland at the mouth of the river Simeto.
The genus *Paratriodonta* features two species*, P. romana* and *P. cinctipennis* in the italian sand dunes. The former is endemic to Italy, where it colonizes dunes, dune heathland and coastal or subcoastal maquis in Latium, from Santa Marinella to Circeo Promontory, usually living on rockrose flowers in spring and summer. The latter has similar ecology, but is only active during spring and is distributed in the Sicilian-Maghrebian areas, with numbers falling in Sicily. Two are the most typical Italian species of shining leaf chafers: *Anomala devota* lives in the western Mediterranean where it colonizes shrub-maquis. In Italy, it is still found on Tyrrhenian dunes where it flies on rock rose and *Ammophila* flowers in late spring and summer. The rare and localized *Hoplia attilioi* (see drawing), is endemic to Sicily and lives only on the sandy beach near Mazara del Vallo where, during warm days in May, it flies among dune vegetation.



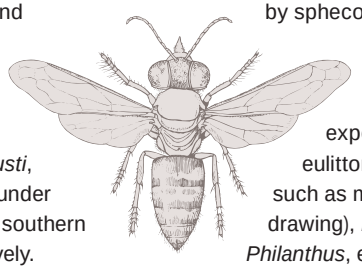
Another interesting species, typical of Sardinia and Corsica, is *Hoplia pubicollis*, which appears on beaches and dunes in spring. Among Dynastinae and the related groups, the most important are the rare and elusive *Calicnemis*. In Italy, they are represented by *C. latreillei* a western Mediterranean species distributed between Tuscany and the Golfo di Taranto, Calabria and Sicily, and the recently described *C. sardiniensis*, endemic to south-western Sardinia. Both species are active between late winter and spring. In the evenings between March and early April, the females and males fly over beaches and dunes, especially between *Ammophila* and *Eryngium*.
Their larvae develop under stranded woody debris covered by sand. Other species which are usually found in coastal and sub-coastal environments and dune vegetation are the small, peculiar scarabs of the genus *Pachypus*,

Pachypus candidae

which features two Italian species, one (*P. candidae*) is endemic to Tyrrhenian areas of central-southern Italy and Corsica, the other (*P. caesus*) lives in Sicily. *Pachypus* are characterized by extraordinary sexual dimorphism: the males are skilled summer fliers, whereas the females are completely apterous (unable to fly) and live in underground tunnels in compacted sand or dry soil at the base of shore vegetation.

● **Leaf beetles**. Italian fauna features about 800 species of leaf beetles, many of which have more or less specialized to life on dunes and dune heathland only because they are phyllophagous (leaf-eating) on dune plants. The most adapted to dune habitats are a few flea beetles, such as *Psylliodes marcidus*, which lives on sandy dunes and is associated with the crucifer *Cakile maritima* on which it is found between March and September. Almost all flea beetles are characterized by great modifications of their rear legs, which are usually swollen to enable them to jump suddenly up in the air. This is how they escape predators and naive entomologists. *Psylliodes maroccanus* and *P. pallidipennis*, of the same subfamily, are very similar to *P. marcidus* and share similar habits, but are only distributed in the western Mediterranean and associated with halophilous crucifers of supralittorals and seaward dunes. The Mediterrranean congener *Psylliodes puncticollis* is associated with sandy beaches and evening primrose, dogbane and grasses. Many species of other subfamilies colonize Mediterranean maquis and are also found in shrub-maquis of dune heathland, where they develop on their typical hosting plants. Among them is the beautiful *Chrysolina americana* (which, in spite of its name, is a Mediterranean autochthonous element), associated with rosemary, lavender and other aromatic herbs frequently found in coastal environments, and other species of the cryptocephaline subfamily.

● **Weevils, apionids and leaf-rolling weevils.** Embryo dunes and ammophila meadows are colonized by small, rare, leaf-eating ceutorrhynchinae weevils, *Ceutorhynchus matthiolae* and *C. pantellarianus*, both associated with the sometimes frequent crucifers of the genus *Matthiola*. The former lives on sandy dunes in southern France and Ionian coasts of Calabria and Basilicata; the latter is distributed on sandy beaches of central-southern Italy and Greece. Embryo dunes often host *Baris*, such as *B. opiparis*, the larvae of which feed on crucifer leaves, particularly *Cakile*. *Sitona variegatus* lives in the same environments and is associated with various small psammophilous leguminous plants of Tyrrhenian shores and areas in Sicily and Sardinia. The congener *S. cachetus* is also dune-loving, associated with leguminous plants and colonizes Sardinia. *Tychius capucinus* is a typical dune element of southern Tyrrhenian coasts which lives on small psammophilous leguminous plants of the genus *Lotus*. Consolidated dunes and warm sandy river mouths are usually colonized by the otiorhynchid *Otiorhynchus juvencus*, a western Mediterranean, nocturnal species which feeds on leaves of the small psammophilous composites of the genus *Anthemis*. In the Adriatic, it lives with the congener *O. ferrarii*, which is also nocturnal and associated with soil under tamarisks. Heathland tamarisks often host various western Mediterranean or Atlantic-Mediterranean species, such as the weevil *Coniatus tamarisci* and a few *Corimalia*, which live on most Italian sandy shores, the colourful cutting weevil *Auletobius maculipennis* (Calabria and major islands) and the very small apionid *Apion tamaricis*, characterized by extremely long tarsi (Sardinia and Sicily). Dunes are also inhabited by other weevils, such as the psammophilous *Philopedon plagiatum* and *Cycloderes canescens*, distributed along sandy Mediterranean coasts, and *Tanymecus submaculatus* and *T. fausti*, both sand-lovers living under bushes, which colonize southern Italy and Sicily respectively. *Leptolepurus meridionalis*, a western Mediterranean species, is found at the end of winter on dunes of central-southern Tyrrhenian coasts, usually under *Ammophila* tufts. Another important species living in sandy dunes and dune heathland is *Phoeniconyx gobbii*, an oxyonine ceutorrhynchinae, which lives on the rare bushy gymnosperm *Ephedra distachya*. This weevil is exclusive to dunes at the mouth of the river Sinni near Policoro in Basilicata and seriously risks extinction. Oxyonines are all associated with *Ephedraceae*, which in turn live in dry, warm, bare, sandy and rocky habitats of good environmental quality on Mediterranean coasts. A new oxyonine of the genus *Paroxyonyx*, of North African origin, has recently been found on southern Sicilian beaches.



Hymenopterans. In spring and summer, many euryecious species of hymenopterans feed on the nectar of flowers of several psammophilous dune species (*Eryngium, Cakile, Calystegia, Euphorbia* and others). Among them are many braconids, ichneumons, chalcidids and large numbers of aculeate insects, such as bees, which play an important role in the cross-pollination of plants. Dune environments, heathland and exposed beaches are usually colonized by sphecoid wasps, solitary predators which do not only nest in dunes, like *Tachytes*, but also in exposed beaches near eulittorals and supralittorals, such as many *Bembix* (see drawing), *Bembecinus, Stizus, Philanthus*, etc. They choose areas where their nests cannot be splashed by high tides. Members of these genera are roughly similar to domestic bees but, unlike them, they fly faster, may suddenly change direction and stop. They catch their prey during flight, and then carry it to their ground nests. *Bembix* supply their nests in a very unusual way: the females carry prey to their nests and lay an egg on top of it. Eggs hatch quickly and the newly-born larvae feed on the

prey, usually flies, paralysed but still alive. Before the larvae finish their meal, the mothers, which occasionally visit the larval cell, bring another dipteran until, after a series of moults, the larvae turn into pupae and then adults.
Cloaked in bright yellow and black, *Philanthus venustus* are sphecid wasps which nest in sand. Their burrows, about 10 cm deep, store mining bees of the genus *Lasioglossum*, which the slightly larger sphecid wasps paralyse with their sting.
Other hymenopterans typically found on exposed beaches are velvet ants, such as *Trogaspida catanensis* and *Nemka viduata* (also known as *Smicromyrme viduata*). The females of this latter wingless species are very colourful, with alternating black, red and silvery-white stripes, a common feature shared by most species of this family.
They may be seen walking slowly on beaches, and most tourists mistake them for large ants. They look for nests of *Bembecinus*, where they parasitize larvae or pupae which they have found digging with their front comb-like legs. Their stings are infrequent and harmless, because their nature is not aggressive and they do not hurt people. The winged males are larger than the females and rest on dune flowers to feed on nectar.
Although solitary, *Bembecinus* hymenopterans usually build groups of dozens, sometimes hundreds of nests, all very close to each other.
They usually feed on sphecid wasps which are similar to them in size, and sometimes prey on the uncommon *Palarus variegatus*.
Beaches often host many bees. If dune heathland is carpeted with *Allium*

Trogaspida catanensis, a velvet ant

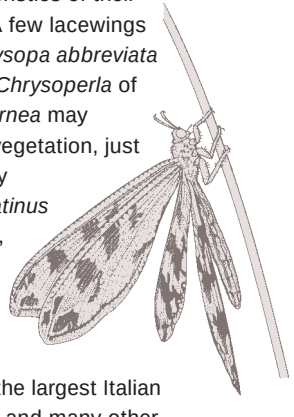
flowers, there are always many sphecid wasps of the genus *Cerceris*, which includes several species. When beaches are visited by tourists, food kiosks and cars are sheltered by canes to keep the sun away. It is extraordinary to see how the holes of these canes are quickly colonized by many hymenopterans, which consider these places their typical homes.
The first colonizers are bees, sphecid, vespoid and cuckoo wasps, which are followed by parasitic hymenopterans such as ichneumons, braconids, chalcidids and others.
The hymenopteran community living in these artificial habitats is composed of mainly euryecious, mobile and ecologically tolerant species.
As soon as living conditions become unfavourable, they are ready to move somewhere else. Another curious fact regards the prejudices and traditional beliefs involving these insects. In the 1920s, the well-known hymenoptera expert Fabio Invrea wrote about Sardinian velvet ants:
"….there, they are known by the dialect name *Valgia*, and are accused of sorcery: their sting is considered to be extremely dangerous…, that is why velvet ants are feared and hated there…; needless to say, the faults of these innocent and pretty creatures are undoubtedly produced by legends. The sting of our local velvet ants, even the largest ones, is far less harmful than that of many other hymenopterans…; however, it is worth noting how similar groundless prejudices are widespread among people who live very far apart and have completely different origins and customs."

Myrmeleon larva

Neuropterans. Many neuropterans typically live in coastal and sub-coastal sandy environments. There, many larvae burrow funnel-shaped snares in the sand. They then wait at the bottom, until small arthropods slip down the mobile walls of the snare, and catch them with their strong, sharp scissor-like mandibles. Besides *Synclisis baetica,* which lives near eulittoral belts but prefers ammophila meadows, the most frequent and characteristic species of neuropterans is *Myrmeleon inconspicuus*, which colonizes dunes, heathland and paleo-dunes with psammophilous vegetal cover throughout Italy. In southern Italy and its islands, it is often associated with the congener *Myrmeleon hyalinus.* Dune heathland hosts the rare *Acanthaclisis occitanica*, which is found on Italian coasts. The same areas and paleo-dunes are colonized by the genus *Creoleon*, such as *C. plumbeus* on Adriatic shores*, C. lugdunensis* on Tyrrhenian, Ionian and low Adriatic beaches, *C. aegyptiacus* in Sicily and *C. corsicus* in Sardinia and Tuscan Archipelago. Recent research work has demonstrated that the genus probably includes various "sibling species",

Funnel-shaped trap of ant lion

which are difficult to identify and are associated with sandy beaches. Although little is known about them, their very presence scientifically proves that these habitats need to be protected. Other psammophilous species frequently found on dunes are *Neuroleon arenarius*, distributed throughout the Mediterranean and in central-southern Italian regions, and the genus *Megistopus*. The larvae of these genera do not burrow funnel-shaped snares, but lie in wait with their pincers emerging from the substrate, ready to snap them shut as soon as prey touches the internal bristles of their mandibles. A few lacewings such as *Chrysopa abbreviata* and various *Chrysoperla* of the group *carnea* may reach dune vegetation, just like the owlfly *Libelloides latinus* (= *L. italicus*), endemic to Italy, and *Palpares libelluloides* (see figure), the largest Italian neuropteran, and many other Mediterranean maquis species.



Dipterans.

● Sciomyzidae. This family is composed of parasitic insects or predatory larvae which feed on land or freshwater pulmonated molluscs. A typical species of ammophila meadows, which may also be found in dry, sandy inland environments is *Salticella fasciata*, distributed in the Mediterranean. It parasitizes on the common *Theba pisana*, a guide species of land molluscs

Robber fly (Diptera)

which colonizes dunes. Another species which colonizes psammophilous and xerophilous shore vegetation, especially near river mouths, is *Euthycera zelleri*, which parasitizes various land pulmonate molluscs.

Lepidopterans. Although lepidopterans are widespread in all land ecosystems, few colonize dune environments. Most species are found in bushy dunes and dune heathland with various types of vegetal cover, where most species are associated with maquis and cliff vegetation and may easily colonize dunes instead of grasses and shrubs.

● Rhopalocera. Sandy dunes in mainland Italy and Sicily frequently host moderately xerophilous and euryecious

Caterpillar of *Charaxes jasius*

Zygaena orana

species which are found throughout the Mediterranean, such as *Pieris edusa* (also known as *P. daplidice*), *P. rapae, Colias crocea, Melitaea phoebe* and *M. didyma, Pyronia cecilia* and *Coenonympha pamphilus*. The two most peculiar species are typical skippers *Gegenes nostrodamus* and the congener *G. pumilio*, associated with various xerophilous grasses and irregularly distributed along the central-southern Mediterranean and western Asia. Although they are not exclusive to these habitats, they are usually found in areas of good environmental quality which are not disturbed by man.

Other butterflies, which frequently fly in Mediterranean maquis vegetation, also colonize dunes, like the large nymphalid *Charaxes jasius,* found in Ethiopia and the Mediterranean. In early and late summer, it may be seen flying over western coasts in Italy. Its larvae are associated with the strawberry tree of coastal and sub-coastal maquis, but they have recently adjusted to developing on trees of the genus *Citrus* (orange and relatives) which are extensively cultivated.

● Burnet and forester moths. Most of them look like nocturnal moths, but they are diurnal, heliophilous and xerophilous. They display bright aposematic colours (which ward off predators, because they contain toxic cyanogenetic glycosides) and live inland in very warm, grassy or rocky slopes, garrigue and mountain meadows.

At least one species, the small, beautiful *Zygaena orana*, of north African origin and active in spring, may sometimes locally be found on the sandy dunes and coastal garrigue along the western Sardinian coastline, where its larvae feed on *Lotus* and other psammophilous leguminous plants. Many other xero-thermophilous and more euryecious *Zygaena* live on flowers of dune vegetation, particularly in sandy areas near sloping coasts and garrigue.

● Owlet moths (noctuids). These moths form part of an important family of nocturnal lepidopterans and include hundreds of Italian species. Their large numbers make them useful biomarkers of the quality of ecosystems. However, not many species are exclusive to dune environments, probably for the above-mentioned reasons, although there are many thermophilous and migrating

Caterpillar of *Brithys crini*

components which annually colonize Italian shores.
The only typical species is *Brithys pancratii* (in the past, it was considered a species separate from *B. crini* and *B. encausta*, the latter being found in Algeria, Malta, Sicily, Apulia and Crete). It also lives in Africa and southern Asia; in the Mediterranean, its larvae are associated with the leaves of pancratium sea lily, a typical amaryllid. Its large caterpillars with aposematic colours may colonize the leaves of their host plant: scorned by all predatory vertebrates (obviously for the toxic substances they contain), they are only preyed on by a few invertebrates like the large carabid beetle *Scarites buparius*.
Lizards, birds and bats feed on the inconspicuous adults of *B. crini*, which fly at night in summer.

Bugs (heteropterans). Bugs are common in Italian dunes, and more or less specialized predatory and phytophagous species are associated with dune vegetation. Many euryzonal species are also frequently found in these environments. The most typical of Italian coastlines, especially on the Tyrrhenian side, is the nabid bug *Nabis reuterianus*, a western Mediterranean predator which hunts almost exclusively on the common dune leguminous plant *Ononis natrix*,

Brithys crini

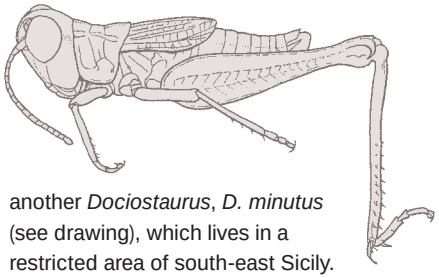
Burrower bug

which hosts the phytophagous plant bug *Phytocoris miridioides.* The base of *Ononis* are also colonized by the predatory lygaeids *Geocoris pallidipennis*, and *Macropternella bicolor*, which feed on seeds of composites found lying at the base of their host plants. Burrower bugs are also typical, such as *Byrsinus albipennis*, which digs in sand near dune shrubs, especially *Ammophila* and *Matthiola,* together with the flat, round stinkbug *Menaccarus dohrnianus*. Another interesting dune stinkbug, *Holcogaster exilis*, found in the southern Mediterranean and associated with *Juniperus*, can only be found on the tiny island of Pantelleria between Sicily and the African coastline. The recently described phytophagous plant bug *Campylloma vendicarina*, which is exclusive to south-east Sicilian coasts and northern Tunisia, is associated with *Juniperus oxycedrus* growing on shore dunes of good environmental quality. The rare, localized phytophagous plant bug *Nasocoris psyche* is endemic to western Sardinia, and is closely associated with the rare and again local dune-living *Ephedra*.

Orthopterans. There are many orthopteran species in dry dune environments, particularly thermophilous and xerophilous acridids. In Italy, the most common genera are *Sphingonotus* and *Acrotylus*. *Sphingonotus personatus* is exclusive to sandy dunes throughout Italy, Sicily and the Greek island of Corfu. In Sardinia, this species is replaced by *Sphingonotus candidus*, with similar ecology. *Acrotylus longipes* has similar ecological needs but is found in circum-Mediterranean areas, especially in Sicily. This species has evolved some peculiar, curious adaptations to warm, sunbaked sandy shore environments, and stands on the boiling-hot sand with three legs stretched out alternately. From sunset to dawn, it buries itself completely in the

Acrotylus longipes

sand, leaving only its eyes and antennae in the air. Many other less specialized species of the same genus colonize sandy dunes, together with a few *Dociostaurus*, such as *D. genei*. Some dune species endemic to Italy, like *Dirshius uvarovi,* are particularly interesting and associated with sandy heathland in a few Italian areas, as is



another *Dociostaurus*, *D. minutus* (see drawing), which lives in a restricted area of south-east Sicily. It is a paleo-endemic component of pre-Quaternary origin, very different from its congeners. Another species endemic to Sicily is *Ochrilidia sicula*, which belongs to an African genus and lives in *Ammophila* and *Elytrigia* dune vegetation. It is slowly disappearing and can only be found in a few areas of the southern and western coasts. A similar species, *Ochrilidia nuragica*, has recently been discovered in the dunes of southern Sardinia, but probably also lives in other dunes and heathland throughout the island. Other common species of Italian dunes are *Sphingonotus coerulans* and the typical *Oedipoda germanica*, a xerophilous euryecious species which lives in many dry, sandy or rocky environments, even inland. Its rear wings have characteristic bright aposematic colours. As regards other groups of orthopterans, *Ephippiger appulus appulus* is endemic to Italy,

Brachytrupes megacephalus

where its large populations live in sandy coastal dunes in Apulia, the decticines of the genus *Pterolepis*, with one Sicilian species (*P. siciliensis*) associated with ammophila vegetation and particularly the exceptional, huge cricket *Brachytrupes megacephalus*, found in the Maghreb, but also in dunes of southern Sicily and Sardinia. This burrowing species, closely associated with sandy environments, is active between late winter and early spring. According to season, it burrows a series of complicated, deep tunnels in consolidated dunes. At sunset, the males stand outside their tunnels facing inside and emit long, loud screeching sounds to attract the females.

Arachnids. There are only a few psammophilous false scorpions on Italian coasts. The most typical is the olpiid *Olpium pallipes*, found in areas of the Mediterranean and on the Atlantic islands of the Canaries, Madeira and the Azores, and throughout Italy, except for the middle and high Adriatic. It lives in dunes and heathland, particularly in ammophila vegetation under psammophilous plants. Other species are frequently found on dunes, although they are not exclusive to them, such as the cheliferid *Dactylochelifer latreillei*, usually found in salicornia vegetation, and the atemnid *Atemnus politus*. Other halophilous species are closely associated with rocky or pebbly beaches.
Phylodromid spiders of the genus *Tibellus*, such as *T. macellus* and *T. maritimus*, which are found in eulittorals, also colonize dunes and heathland grasses. Various psammophilous and more or less sea-loving wolf spiders (*Arctosa* spp., *Alopecosa* spp., and others) live in both eulittoral and dry extralittoral areas. Arid, sandy supralittorals and dunes host thermophilous and xerophilous species belonging to various families (especially jumping spiders, cobweb weavers, crab spiders and oonopids), although not exclusively. A typical component of all Italian coasts, from Liguria to Istria, is the thermophilous araneid *Argiope lobata,* which usually weaves large, vertical cobwebs in the highest dune and heathland bushes. The common daddy-long-legs is a typical predator in dunes.

Centipedes (chilopods). Most centipedes live in damp environments, and therefore only a few colonize dry dunes. Some widely distributed species are found in open dune heathland, such as *Pachymerium ferrugineum* and *Henia bicarinata*, two geophilomorphs, as well as a few more thermophilous lithobiomorphs like *Lithobius cassinensis* or the small, elusive scolopendromorph *Cryptops trisulcatus.*

Millipedes (diplopods). There are few millipedes in sandy dune environments. Apart from a few euryecious species, already mentioned in the section on eulittorals (e.g., *Lophoproctus jeanneli, Polyxenus lapidicola, Stosatea italica*), found in the dampest areas under dune and heathland bushes, there is the julid *Ommatoiulus oxypygus*, moderately euryecious, which colonizes sheltered dunes and heathland in Calabria, Sicily and its accompanying islands, and Malta. The congener *O. sabulosus*, found throughout Europe at various altitudes, prefers open, warm environments, including sand dunes.

Molluscs. Terrestrial molluscs are quite diversified in dune environments, and many species have adapted to life on the beach. Some of them are so numerous that scientists have often used this group as a good biomarker for the quality and dynamic evolution (natural and anthropic) of coastal communities. The dominant species in sandy dune environments throughout Italy is the helicid *Theba pisana*, which is so widespread, particularly in ammophila vegetation, as to be not only the reference point and guide-species for all invertebrates (*Thebetum pisanae*

Theba pisana

"association"), but also the fulcrum of the entire ecosystem in recycling and enriching the soil with calcium ions by means of the continual accumulation and pulverization of large numbers of its empty shells in dunes and heathland. This species, found throughout Mediterranean and Atlantic areas, is usually associated with a few *Cochlicella*, such as *C. conoidea* (a western Mediterranean species found all over Italy) and, occasionally, with *C. acuta*, together with various species of other genera such as *Monacha*. In more compact, limestone-marly soils of

dune heathland, *Theba pisana* is replaced by species such as *Trochoidea pyramidata* or *Cernuella virgata*. Instead, the already-mentioned *Cochlicella acuta*, a Mediterranean species, is typically found in dry dune heathland, together with a few *Cernuella, Papillifera* and sometimes the more mesophilous *Xeromicra apicina.* Some endemic or sub-endemic Italian species living in fragmented or restricted areas are of great naturalistic value. Examples are: *Ichnusomunda sacchii*, found only on the beach of Is Arenas and a few other sandy dunes of western Sardinia; *Polloneriella contermina*, typical of dunes in Latium (particularly in the province of Viterbo) and western Sardinia; *Cernuella aradasi*, limited to sandy dunes near Faro di Messina, Sicily; and the relict *Xeromunda durieui*, which lives on dunes in Apulia (near the city of Taranto) and northern Africa.

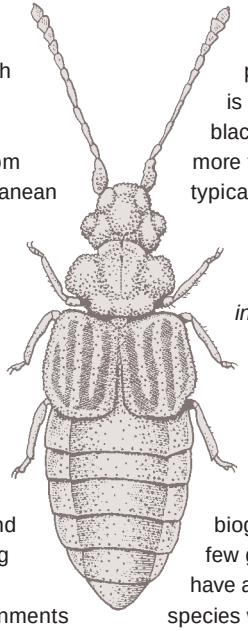
Communities of silty-muddy beaches, salicornia vegetation and banks of heathland lagoons

Beetles.

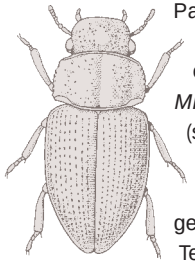
● Ground beetles (carabids)**.** Ground beetles are an important group of small predators on damp, sandy coastlines. Among the most significant are tiger beetles, like the rare *Cassolaia maura*, a Spanish-Maghrebian species which in Italy is only found in Sicily and Calabria along the banks of brackish coastal lagoons, and two *Cephalota* species: *C. circumdata*, a Mediterranean species found in salt-pans, brackish marshes and coastal lagoons near Taranto (Apulia), Orbetello (Tuscany), in Sardinia and probably also Sicily, and the Spanish-Maghrebian *C. littorea*, found in Sicily and Sardinia with its subspecies *goudoti*. Other important species are the silt-loving *Myriochile melancholica*, found in Africa, India and the Mediterranean, which lives in Italy as far north as Tuscany and on the islands, particularly in muddy banks of brackish lagoons and river mouths. Salicornia communities do not contain only tiger beetles, but also various species of the genera *Pogonus, Pogonistes, Syrdenus*, and also *Tachys scutellaris, T. dimidiatus*, a few *Dyschirius* and *Dyschiriodes, Daptus vittatus, Notaphus ephippium* and a few *Amara*, such as *A. metallescens,* found in Sicily, Sardinia and salt-pans near Tarquinia (north of Rome). Most are Mediterranean or western Mediterranean species, seldom found in the eastern Mediterranean but extending to central Asia. Among the most typical, besides *Daptus vittatus*, are the small ground beetles of the genus *Dyschiriodes* (like *D. fulvipes* in Sicily, *D. importunus* in southern Italy, and *D. salinus* and *D. intermedius* near river mouths), which are usually found under crusts of mud and prey on sand- and mud-loving rove beetles of the genus *Bledius*. Nearby damp environments with typically hygrophilous, less halophilous vegetation such as phragmites and rushes contain many other species, particularly the bembidiines *Stenolophus* and *Acupalpus*, a few species of *Paradromius* and *Drypta,* and large numbers of hygrophilous, euryecious components from nearby environments.

A *Tenthyria* (darkling beetle) feeds on remains of a tiger beetle

● Rove beetles (staphylinids). Dune heathland, banks of temporary pools, salicornia meadows and all brackish environments, where sand blends with silt, contain interesting communities of rove beetles. There are many components of the oxyteline subfamily which feed on microalgae, including some species of the genera *Bledius* (about a dozen in Italy) and *Carpelimus* (six Italian species, all very small). Instead, *Throbalium* (two species, less than 0.5 cm long), *Cryptobium*, a few *Philontus* and *Brundinia* are predators. The largest predator in these environments is *Orthidus cribratus*, a shiny black-bronze rove beetle, which is more than 1 cm long. The most typical inhabitant of brackish ecosystems, in spite of its small size (about 2.5 mm), is the mysterious *Euphanias insignis* (see drawing), with two subspecies: one found throughout Italy and Sicily, the other only in Sardinia and Corsica. The rove beetles living in these environments are also interesting from the biogeographical viewpoint, as a few genera (*Throbalium, Remus*) have a large number of allopatric species which have not yet been accurately studied or interpreted.



● Water scavengers (hydraenids). Many hydraenids live in salicornia vegetation and plant debris under halophilous plants, especially near river mouths. The most interesting are halophilous species of the genus *Ochthebius*, such as *O. viridis*, *O. subpictus*, etc., found in Sicily, Sardinia and along the Ionian and Adriatic coasts.



Particularly interesting is the very rare ochthebiine *Micragasma paradoxum* (see drawing), the only Mediterranean component of a genus going back to the Tethyan period, which includes species found in southern Asia, the Greek island of Corfu and coasts near Taranto. It feeds on monocellular algae and lives in damp plant debris of coastal salicornia vegetation.
It is undoubtedly one of the most significant and endangered beetles of all European fauna.

● Handsome fungus beetles (endomychids). Some of the unusual detrivorous and microphagous components of this small beetle family are very interesting (see *Beach markers,* p. 25), as they include a large number of genera and species associated with woodland fungi, especially tropical ones. Although usually very rare, at least three hygro-psammo-halophilous species of the genus *Dapsa* live in the debris of salicornia vegetation, but also in stranded algal and plant debris on eulittorals of Italian coastal lagoons and river mouths. *Dapsa opuntiae* is found in central-southern Italian regions, and the exceptional *Dapsa obscurissima* (= *D. tyrrhena*) may only be found in a few areas in Tuscany (near Orbetello), Latium (between the mouth of the Tevere and the bay of Formia), northern Tunisia and Algeria. Salicornia and phragmites coastal vegetation in Italy often contain *Dapsa trimaculata* which, in southern Italy, is associated with *Ancylopus melanocephalus,* of similar ecology but found in southern Mediterranean and Asian areas.

● Sap and pollen beetles (nitidulids). There are few sap beetles and kateretids in dune environments. Most of them are damp-loving, associated with hygrophilous but poorly halophilous habitats with rushes, such as *Kateretes* (kateretids) and *Meligethes* (pollen beetles) of the group *M. lugubris*, associated with *Mentha* spp.. The most interesting species is the rare *Kateretes dalmatinus,* found in the eastern Mediterranean with Italian relict populations in damp, sandy heathland near Trieste, and on the shores of Apulia, the Ionian coast of Basilicata, Calabria and Sicily.

● Shining flower beetles (phalacrids). There are a few shining flower beetles in coastal rushes, mainly hygrophilous species of the genera *Stilbus* and *Phalacrus*, which are not closely associated with coastal environments and are usually only found on hygrophilous grasses.

● Darkling beetles (tenebrionids). As already seen, darkling beetles tend to be xerophilous, and therefore few live in damp, silty salicornia vegetation. Many are ubiquitous, ecologically tolerant species which visit these areas. The only frequent species is the polytypic *Blaps nitens*, found in the southern Mediterranean and Sardinia with its subspecies *mercatii*, which lives in brackish salicornia vegetation, not necessarily near the coast. A few species of *Xanthomus*, typical of damp littorals, are sometimes found in dune heathland.

● Leaf beetles (chrysomelids). Among leaf beetles, extensively described in the section on dune communities, is

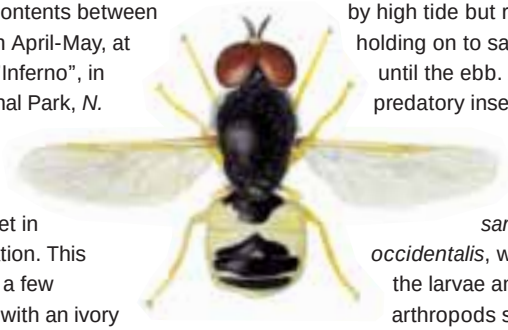
Xanthomus pellucidus

Chaetocnema tibialis, found in salicornia vegetation in central Asia and the Mediterranean, active from April to October and associated with chenopods in various environments. Warm, damp heathland near brackish lagoons hosts *Asiorestia impressa*, a Mediterranean species, which may be found from April to October on grasses and *Limonium* spp. (Plumbaginaceae). Among tortoise beetles, with their typical flat, sunken bodies, wide pronotum sides and wing-cases, is *Oxylepis deflexicollis*, of the western Mediterranean, found between May and July. It is associated with halophilous ecosystems with chenopods of the genera *Salsola, Suaeda* and *Salicornia*. Among leaf beetles is *Chrysolina schatzmayri*, a rare species endemic to Italy, found on the Veneto coasts and associated with the halophilous composite *Inula crithmoides*. The galerucine *Diorhabda elongata* and cryptocephaline *Stylosomus tamarisci* live on tamarisk.

● Weevils (curculionoids). Salicornia vegetation frequently hosts indirectly halophilous weevils. Among them is the small ceutorrhynchine *Pseudophytobius acalloides*, found in western Atlantic and Mediterranean areas and in Sardinia, associated with the leaf parenchyme of halophilous chenopods of the genus *Suaeda*.

Neuropterans. Neuropterans seldom live on damp, sandy, brackish coasts or sub-coasts. But two species are *Megistopus flavicornis*, found throughout the Mediterranean, and the rare, significant *M. mirabilis*, first found in Sinai (Israel) and recently discovered on the central Tyrrhenian coast of Latium between the Circeo promontory and the Italian President's country residence at Castelporziano.

Dipterans. Banks of coastal lagoons and pools, salt-pans, salicornia vegetation and river mouths often host hygrophilous species of shore flies, also found on damp beaches, such as *Ephydra bivittata, E. flavipes, Scatella subguttata, Scatella* spp., *Scatophila modesta, Asmeringa inermis* and many others. Although soldier flies do not have aquatic larvae, they are mentioned here for their peculiar biology, i.e., they are associated with salty environments, especially salicornia vegetation. Various species of larvae of the genera *Nemotelus* and *Stratiomys* are adapted to salt contents between 80 and 100 g/l. In April-May, at the "Pantani dell'Inferno", in the Circeo National Park, *N. notatus* (see drawing) may be captured with a butterfly net in salicornia vegetation. This soldier fly only is a few millimetres long, with an ivory white belly. In Italy, *Nemotelus crenatus* is found in the Lagoon of Venice, and the now rare *N. longirostris* and *N. punctatus*, with particularly large snouts, in a few sites in Sicily and Sardinia. In Italy, all species of *Nemotelus* are endangered, and risk extinction due to the degradation and gradual destruction of their habitats. The situation is much worse in the tourist resorts of the high Adriatic, where massive, repeated anti-mosquito spraying is carried out.



Bugs (heteropterans). Bugs often live in damp, silty-sandy environments, with both predatory and more or less specialized phytophagous species, associated with salicornia vegetation and rushes growing in brackish soil. Many hygrophilous euryzonal species often visit these areas. Among the most common species found along coasts (except strictly aquatic species) is *Halosalda lateralis*, a predatory shore bug of the European Mediterranean area, which lives not only in brackish, sandy-silty soils and salicornia vegetation near brackish lagoons, but is also often found on eulittorals near river mouths. This species moves jerkily, like the carabids of the genus *Cicindela*, with which it often lives. On beaches, it may be submerged by high tide but remains still, holding on to salicornia stalks until the ebb. Another predatory insect in salicornia vegetation is the nabid bug *Halonabis sareptanus occidentalis*, which feeds on the larvae and adults of small arthropods sheltering under halophilous chenopods. The same environments, particularly in southern Italy, host other predators like the plant bugs *Phytocoris salsolae, Polymerus cognatus* and *Orthotylus moncreaffi*, and the lygaeid *Engistus boops*. Among phytophagous organisms, one of the most typical is the gaudy red and green stinkbug *Brachynema cinctum*, associated with salicornia meadows and halophilous chenopods, which lives in Sicily, Sardinia and their small islands.

Orthopterans. Many orthopterans live in damp, brackish interdunal habitats, salicornia vegetation and hygrophilous shore vegetation. Many species are damp-loving, widely distributed, and not

Roeseliana brunneri

always associated with sandy environments; others are important from the conservation viewpoint, as they are endemic or sub-endemic to restricted Italian areas. Among them are the bush crickets (tettigoniids) *Roeseliana brunneri* and *Zeuneriana marmorata*, endemic to Venezia Giulia, the Lagoon of Venice, and beaches near Ferrara, but now limited to a few relict, endangered populations of sandy shallows in the Lagoon of Venice. Both species, associated with the grasses of these brackish, sandy environments, risk extinction and must be protected at all costs. Their survival is threatened by the combination of drainage works, destruction of their habitat, uncontrolled floods, and insecticides used in agriculture.
Endemic to western Sicily is *Pterolepis elymica*, and Sardinia hosts the similar *P. pedata*. Other populations associated with the same habitats but more widely distributed are *Epacromius coerulipes, E. tergestinus, Chrysochraon dispar, Parapleurus alliaceaus, Paracinema tricolor, Aiolopus thalassinus*, etc.

Millipedes (diplopods). Salicornia vegetation and sandy banks of interdunal lagoons only host a few hygrophilous euryecious species, usually living in man-made areas, such as *Brachyiulus pusillus,* found on the banks of lagoons and pools.

Arachnids. There are a few predatory false scorpions (some already mentioned in the section on dune environments) in salicornia vegetation, such as the cheliferid *Dactylochelifer latreillei*, usually found in the high Adriatic with *Rhacochelifer disjunctus*, and the atemnid *Atemnus politus:* this is a steppe species which lives in the Mediterranean area, central Asia, and the Atlantic islands, typical preferring salty soils, and which in Italy (e.g., along the Adriatic) is a coastal psammo-halophilous organism. There are many spiders in salicornia vegetation and the damp, sandy banks of brackish lagoons. Besides the already-mentioned sand-loving wolf spiders, which usually visit these areas when they are dry, hygrophilous vegetation hosts many ubiquitous and moderately hygrophilous species, such as crab, dwarf and cobweb spiders, and phylodromids.

Molluscs. Salicornia vegetation and the transitional land-water areas of damp, interdunal environments host pulmonate molluscs like *Myosotella myosotis* (typical of stranded debris on damp, sandy-gravelly eulittorals) and *Auriculinella bidentata.* Psammo-halophilous vegetation hosts *Theba pisana, Cernuella virgata* and *Cochlicella acuta*, which are more xero- and halo-resistant than psammo-hygrophilous.

As we have already seen, the numbers and total biomasses of sand-loving invertebrates along coasts are rather small.
It is therefore not surprising that there are only a few specialized species of vertebrates, mostly predators. Usually, only euryecious and widely distributed vertebrates occasionally visit beaches and dunes, mainly looking for the stranded remains of large sea animals.
For most larger animals, elusive and seldom caught unawares by observers when far from safe and easily accessible shelters, dune systems and beaches are too bare and offer too little protection.
The situation has recently worsened, as coasts have become heavily populated, especially during the reproduction period of some species. For mammals, the difficulty of burrowing safe dens in soft, mobile sandy soil has certainly contributed to the fall in natural beach populations.
But let us briefly examine the various species which can usually be found on Italian beaches and dunes, and mention the several cliff birds which often visit coastal lagoons. These diversified, numerous bird communities, associated with aquatic invertebrates living in soft soils, have large biomasses (sustaining important food chains) but are only occasionally found on coastal sandy beaches and dunes.

A fox caught unaware on a beach of the National Park of Uccellina (Tuscany)

Amphibians. The only Italian amphibian which is sometimes found on sandy dunes and heathland, as far as exposed beaches near the waterline, is the common green toad *Bufo viridis*. This species, found in palearctic areas and throughout Italy, including its islands, from sea level up to 2000 m in the Alps, may reproduce even in the small, freshwater or slightly brackish lagoons along the coasts. Toads are usually seen on damp, cool days and nights even in summer, as they wander across dunes in search of small arthropods. Lack of spring reproduction sites and the biological quality of waters may limit their presence. Dunes in Sardinia and central Italy occasionally host tree toad (*Hyla* spp.), visible particularly at night and on rainy days.

Reptiles

● Lizards. Sandy dunes in Italy and its islands always host Italian wall lizard (*Podarcis sicula*), which is also found in the Balkans and usually lives with the western green lizard (*Lacerta bilineata*, in the past known in Italy by the name of *Lacerta viridis*). During the day, they both prey on the adults and larvae of many small, sand-loving invertebrates. Sardinian and Sicilian dunes and small beaches surrounded by rocks occasionally host *Podarcis tiliguerta* and *Algyroides fitzingeri* (Sardinia), *Podarcis wagleriana* (Sicily) and *P. raffonei* (endemic to the Eolian Islands). On the “Isolotto dei Conigli” (“Rabbit Island”), one of the Pelagic Islands (which include Lampedusa, Linosa and Lampione, south of Sicily), beaches sometimes also host *Psammodromus algirus*, a Spanish-Maghrebian species which lives in dry environments on compact, rocky soils in northern Africa from sea level to 2000 m.
● Skinks. Dunes and heathland in Sardinia and Sicily are home to ocellated skink (*Chalcides ocellatus*) which can live in open, bare, sandy environments but which prefers inland sub-coastal areas.
● Snakes. The most typical species that colonize Italian sand dunes are the common, versatile rat snake (*Coluber viridiflavus*) and the rarer four-lined snake (*Elaphe quatuorlineata*), particularly where Mediterranean maquis covers dune and heathland. Four-lined snake only lives on central-southern Italian coasts and needs dense maquis in which to hunt, although it often wanders to damp interdunal environments. The same habitats mainly of northern Italy contain *Coronella girondica* (Riccioli rat snake). Sicily and the southern Ionian host the beautiful leopard snake (*Elaphe situla*), generally found in southern Italy, the Maltese islands, the Balkans, and eastwards as far as Anatolia and the Caucasus. In south-west Sardinia, dunes and heathland sometimes reveal the rare *Coluber hippocrepis* (horseshoe whip snake), distributed in the western Mediterranean. Sandy beaches in western Liguria and the Pelagic Islands exceptionally host the large Montpellier snake (*Malpolon monspessulanus*) and the island of Lampedusa false smooth snake (*Macroprotodon cucullatus*), the

Coluber hippocrepis

only two Italian species of venomous opisthoglyphs (snakes whose venomous teeth are set very far back in their mouths). The common adder (*Vipera aspis*) sometimes visits dunes in Italian regions.

● Tortoises. Dune and interdunal environments of western Italy, from Liguria to Sicily and Sardinia (and along the Ionian coastline as far as Taranto) often host common tortoise (*Testudo hermanni*), in the past frequently found in dry environments with the poor vegetation of garrigue and rocky meadows, but now disappearing due to the destruction and degradation of its natural habitat, and the continual taking of its young, which are sold as garden or terrarium animals. Common tortoise is still frequent on dunes and heathland in central-southern Tuscany, Campania, Calabria, Basilicata, Sardinia and Sicily. It feeds on leaves and creeping, succulent sprouts, and sometimes on small phytophagous, ground-living invertebrates.

● Turtles. Large turtles need quiet, sandy beaches to lay their eggs. Only one of the three Italian species can reproduce in Italy, the common sea turtle, *Caretta caretta*. The other two - green turtle (*Chelonia mydas*) and the often huge Atlantic leatherback turtle (*Dermochelys coriacea*), frequently found in the Mediterranean and Italy (especially in the lower Tyrrhenian and Canale di Sicilia) - do not seem to reproduce in Italy, although there are doubts regarding the presence in Sicily of nesting sites of the the Atlantic leatherback turtle. The first definite description of the reproductive sites of the sea turtle was written by Doderlein in the late 19th century: "*…among marine turtles, or Thalassemyidae, the sea turtle is common in Sicily … the only Mediterranean representative of the horny turtles which live in the vast Ocean. In spring, many individuals move to the sea between Sicily and its smaller islands to lay their eggs, the precious source of their very survival* …".
At present, turtles in Italy reproduce only in clearly identified areas near Gela and Mazara del Vallo (Sicily), on the islands of Lampedusa and Linosa, and several sites included in recent counts in Ionian Calabria (e.g., near Isca Marina). Nests of *Caretta caretta* have also recently been found on the Adriatic coastline of Apulia near the natural park of Laghi Alimini (Otranto), and other nesting sites on beaches of Ionian Basilicata cannot be ruled out. According to recent surveys, likely only ten nests are dug in Italy each year - an insignificant figure when we consider the total annual count of about 5000-6000 nests in the Mediterranean (particularly east and south).

Common sea turtle (*Caretta caretta*)

Caretta caretta is a cosmopolitan species found in intertropical seas and southern Italian waters. Although it often lives in shallow waters, sometimes reaching the mouths of rivers, it is also typical of often deep parts of oceans. Usually carnivorous, turtle feeds on crustaceans and molluscs, and occasionally on fish and posidonia leaves. Eggs are laid between May and August, with peaks in June. The females swim ashore during the night and choose dark, quiet, deserted areas in the upper parts of the beach, where they dig their nests, near embryo dunes without pioneering vegetation.
They lay about 70-100 eggs, each of which is about 4 cm long. After covering the hole, the females go back to the sea, and a fortnight later they can dig another nest in the same or in a different area. Eggs are usually laid every 2-3 years, and in that year each female can lay eggs between one and five times (generally 2-3). Although they prefer coasts where they have already laid their eggs, turtles do not depend on particular areas. All the eggs hatch at almost the same time after a period varying between 40 and 80 days, depending on the temperature inside the nest, average external temperature of the area, exposure to the sun, and mineral composition of the sand. Eggs hatch late on white limestone beaches which reflect the sun's rays, and early on volcanic beaches with dark sand which absorb sunlight. When the external temperature falls (usually at night, early morning, or on cloudy, rainy days), the young leave their nests *en masse* and instinctively head for the sea.
The highest risk for turtles while they remain on land is predation of eggs and young. Nests are often uncovered by ubiquitous predatory mammals which occasionally wander across dunes, such as foxes, badgers and, particularly near towns, groups of stray dogs. During their journey from the dunes to the sea, the baby turtles are actively preyed on by sea and land birds, particularly seagulls.

Birds. The most typical birds on beaches, particularly on intertidal and eulittoral belts, are shorebirds (charadriiforms), such as Kentish plover (*Charadrius alexandrinus*), sanderling (*Calidris alba*) and red-backed sandpiper (*Calidris alpina*). Other frequent birds are ringed plover (*Charadrius hiaticula*) and turnstone (*Arenaria interpres*), which is usually found from rocky, pebbly beaches to small, sandy bays. The most typical species is Kentish plover, which nests on sandy eulittorals or supralittorals, or near brackish lagoons. It burrows in sand or silt covered with grass, twigs, banks of posidonia, and algae. Between late March and June, it lays brown or greenish eggs with black or grey spots and streaks, about 32 x 25 mm, on which both parents sit for more than three weeks. The species is still common in quiet areas, especially in the high Adriatic. It feeds on insects, both larvae and adults, crustaceans (especially sand fleas), molluscs, and small stranded

Nest of Kentish plower (*Charadrius alexandrinus*)

vertebrates and invertebrates. Sanderling and red-backed sandpiper are winter migrants, and in cold months colonize beaches looking for animal remains and sand-loving arthropods. After feeding along the waterline, they rest together on quiet, sheltered beaches. Ubiquitous species of seagulls (*Larus* spp.) often visit beaches in search of small stranded animals. Salicornia

Kentish plower (*Charadrius alexandrinus*)

Oyster catcher (*Haematopus ostralegus*)

Common pratincole (*Glareola pratincola*)

vegetation and salt-pans host many other typical species of coastal and sub-coastal lagoons and river mouths, such as oyster catcher (*Haematopus ostralegus*), Eurasian lapwing (*Vanellus vanellus*), blackwinged stilt (*Himantopus himantopus*), avocet (*Recurvirostra avosetta*), and large numbers of shorebirds associated with damp, plain environments, like little stint (*Calidris minuta*), black-bellied plover (*Pluvialis squatarola*), redshank (*Tringa totanus*; typical of salicornia vegetation in the Lagoon of Venice, with hundreds of nesting couples), spotted redshank (*Tringa erythropus*), curlew (*Numenius arquata*) and many others. Worthy of mention is common pratincole (*Glareola pratincola*) which, although not exclusive to Italian coastal brackish environments, mainly reproduces here. Oyster catcher is of great conservation value, as its reproductive sites in Italy are disappearing: only about 30 couples now nest in the Po Delta. A few species of infrequent seagulls, such as great black-headed gull (*Larus melanocephalus*) and slender-billed gull (*Larus genei*) reproduce in coastal salicornia vegetation (in Italy, in the Valli di Comacchio, near the Po Delta). Overall, most shorebirds are widely distributed or cosmopolitan, and colonize beaches throughout the world. However, coastlines of good environmental quality, where these birds reproduce, are becoming restricted, and also in Italy the most typical nesting areas for many species have become highly important from the naturalistic viewpoint (particularly the Lagoon of Venice, the Valli di Comacchio, and the brackish lagoons of the mid-Tyrrhenian coast, southern Sardinia and Sicily).
Dunes and heathland host large numbers of passerines, many of which are ubiquitous, such as redbreast (*Erithacus rubecula*), blackcap (*Sylvia atricapilla*), blackbird (*Turdus merula*) and mavis (*Turdus philomelos*) which visit heathland in autumn, feeding on berries of the Mediterranean maquis. The most typical resident species are other sylviids, such as Sardinian warbler (*Sylvia melanocephala*), Dartford warbler (*Sylvia undata*), and particularly the infrequent La Marmora's warbler (*Sylvia sarda*), which

Dartford warbler (*Sylvia undata*)

lives in Sardinia and a few islands of the Tuscan Archipelago, and is endemic to western Mediterranean islands, large and small. Dune heathland containing old, hollow trees, remains of man-made constructions (high dry-walls, abandoned stone houses), or rocky bulwarks sometimes host roller (*Coracias garrulus*), a beautiful coraciiform usually found in open, sub-coastal countryside, which feeds on large numbers of arthropods, small terrestrial vertebrates and, in autumn, on fruit and berries of the Mediterranean maquis. Another beautiful coraciiform**,** bee-eater (*Merops apiaster*) is found in the Mediterranean, and specializes in preying on flying insects (especially hymenopterans).
It may often be seen flying across dunes, particularly near consolidated alluvial soil along sloping coastlines, which are best suited to its underground nests (eroded edges of paleo-dunes, upstream banks near river mouths, walls of small limestone-marly ravines, etc.).

Mammals. Except for species closely connected with the presence of man (called synanthropic), the less common but widespread wild rabbit (*Oryctolagus cuniculus*) and a few moles (*Talpa europaea, T. romana*), which sometimes burrow their dens and tunnels in consolidated sandy soil of coastal heathland (especially where they contain large numbers of earthworms), almost all mammals on coastal sandy beaches are occasional or periodical visitors.
Porcupine (*Hystrix cristata*) sometimes wanders across dunes and beaches, especially when they are near consolidated heathland with Mediterranean maquis and woodland.
However, the most typical species is wild rabbit, which is still frequently found in dune heathland and paleo-dunes of many coastal and sub-coastal beaches of relatively good environmental quality, particularly in Sicily and southern Sardinia, although its numbers are falling in the rest of Italy, due to both natural and

Stone-marten (*Martes foina*)

anthropic causes. Wild rabbit feeds on grasses, buds, sprouts, roots of dune plants and shrubby maquis.
The most typical occasional species are ubiquitous, medium-sized and large predators: among the canids is fox (*Vulpes vulpes*), among the mustelids, the elusive badger (*Meles meles*, found almost everywhere on coastlines deserted by man), the small stone-marten (*Martes foina*) and weasel (*Mustela nivalis*). Occasional insectivores include hedgehog (*Erinaceus europaeus*). Most of these mammals are found on dunes and beaches in winter, spring and autumn, especially at night or dawn, feeding on carrion (fish, seabirds, molluscs, etc.) or terrestrial arthropods (especially beetles) which, as we have already seen, are particularly active at night and in winter.
Apart from rats and small rodents, the only relatively large live prey for hunting carnivores are wild rabbit and the already mentioned shorebirds.
A few insectivorous micro-mammals, such as shrews of the genera *Sorex*, *Crocidura* and *Suncus*, and rodents of the genera *Apodemus* and *Eliomys,* may be found in consolidated heathland, although these species are not usually associated with coastal sandy environments. The same cannot be said about a few synanthropic**,** ubiquitous species, e.g., among rodents, black rat (*Rattus rattus*) and house mouse (*Mus musculus*), frequently found on dunes and heathland often visited by man. Recently, also coypu (*Myocastor coypus*), a large South American rodent acclimatized to Italy and often mistaken by non-experts for otter, has often been seen near dunes at the mouths of rivers.
Among bats, there are many common, ubiquitous species (*Pipistrellus* spp., *Myotis* spp., and others) that fly on beaches and dunes, especially in spring and summer, at dusk or in the evening, when many sand-loving insects attracted by light (houses, lamp-posts, headlights, etc.) fly over dunes and the tops of heathland shrubs and trees.

Conservation and management issues

PAOLO AUDISIO · GIUSEPPE MUSCIO · SANDRO PIGNATTI

■ Risk for dunes and sandy beaches

Beaches and dunes apparently do not have any particular economic value, as they are unstable, easily eroded, subject to storms and bad weather, and therefore not suitable for building purposes. Agriculture (mainly vegetable growing) is only feasible inland and on interdunes, i.e., far from true dunes. However, Mediterranean beaches, particularly Italian ones, have recently been so severely jeopardized as to be irreversibly altered. Damage to beaches is caused by poor land management, and is aggravated by the direct and indirect consequences of mass tourism. The impact is particularly evident when damage is due to works such as excavation and clearcut erosion of many beaches, and the numbers of biotic communities not only fall, but also lose their peculiarities when euryecious, tolerant and widely distributed animals replace them.

The introductory chapters have already explained how coastal sandy ecosystems, by their very nature and location, must face difficult and changing situations over both short and lengthy periods. We have also seen that they have great capacities for “self-repair” and resilience, from the hydrogeological, geomorphological, floristic and faunistic viewpoints. This may lead us to think that, although severely misused or even completely destroyed by man, coastal sandy environments might, sooner or later, spontaneously recreate good-quality beach ecosystems. These hypotheses are partially true (although they may require years or centuries), but they cannot be applied to short-term projects which involve man directly.

After analysing the main dangers threatening coastal sandy environments in Italy and the eventual naturalistic consequences, we shall discuss possible conservation, management and rehabilitation strategies.

Let us now analyse what are called “the laws of sandy beaches”, which govern many geomorphological risk mechanisms in beach-dune systems and which must therefore be taken into account.

- Beaches and dunes need waves, tides and sea winds free from artificial obstructions if they are to be formed and modelled, and teem with life. Without

Drift wood after a storm

A natural beach (Calabria)

these natural elements and events dunes cannot form, because it is difficult otherwise for sand to be accumulated by the sea, dry up, be carried by winds, and accumulate inland. Dunes in artificially enclosed seas without tides and artificially protected against winds and waves, easily undergo natural deterioration. The same occurs if the so-called “wandering dunes”, because of unnatural obstacles, cannot move freely to and fro between the margins of the exposed beach and the base of consolidated dunes.

- The formation, modelling and life of dunes depends on beaches, the sand of which must completely dry up in exposed areas, giving rise to incoherent grains; if, for any reason, this does not happen (or if sand dries up, forming surface crusts), winds cannot carry and accumulate it inland.
- If the natural self-repair mechanisms of beach-dune systems are definitively altered by the induced variation of any environmental parameter, no artificial intervention (beach enrichment, construction of artificial dunes, etc.) can ever put an end to damage like erosion or burial, unless the origins of the unbalance are solved at the same time.

Macroclimatic risk. Since the late 18th century, the slight but gradual rise in mean annual temperature - the well-known “greenhouse effect” - together with the rise in sea level, have been the most disquieting factors threatening sandy beach ecosystems. As already mentioned, the rise in sea level as a consequence of higher mean temperature is partly due to meltwater from the Arctic and Antarctic ice-caps and glaciers of the main mountain ranges, and partly to the lower density of water itself, which causes a slight but globally appreciable expansion in volume.

However, notwithstanding the actual alternation of warm and cold periods, already discussed in the chapters on paleo-geography and paleo-climatology, it is important to note that, for the last 6000 years or so, the climate seems to have stabilized (as has sea level). Comparisons with paleo-climatic reconstructions of the whole of the Pleistocene reveal that these periods of relative stability are analogous to those preceding the beginning of glacial cycles. Some climatologists actually think that a new, more or less intense glaciation is not very far off.

This hypothesis seems to be in contrast with the justified alarm caused by the recent rise in annual temperature, attributed to the greenhouse effect. However, we must bear in mind that temperatures only first began to be recorded reliably in the 18th century, a particularly cold period. The recorded temperature rise that followed may therefore indicate that the Earth’s climate was simply settling to higher temperatures - a kind of pre-glacial climatic stability, as hypothesised above.

We may thus observe that lower sea levels (associated with lower mean temperatures) would slowly induce beach-dune systems to move seawards. This process would not be particularly traumatic, as soils would gradually modify to adjust to their coastal communities. However, at present, even a short-lived temperature rise (of a few years or more) would raise sea levels everywhere. Many well-preserved sandy beaches actually border on large towns, roads and natural rocky areas, which psammophilous coastal biocenoses cannot colonize if moved inland.

The speed at which waterlines move inland, combined with significant macroclimatic modifications in the Quaternary, amount to an estimated 100 metres in 10,000 years, or about 1 cm/year. In less than 10 years, a 10-centimetre drift on particularly flat beaches would make the sea advance a few metres inland, thus affecting beach-dune systems.

It is very probable that the greenhouse effect will cause a rise in sea level. Climatologists have differing opinions, and although catastrophic events were forecast 20 years ago, scientists now agree that the sea level will probably rise by about 50 cm by the year 2100. If this proves correct, many sandy dune ecosystems will be completely destroyed locally. This will definitely occur on beaches without narrow, sloping inland belts which might be used by biotic communities as “buffer zones”.

The mystery of San Rossore

Sandro Pignatti

In the 1970s, many pine-trees died along the Tyrrhenian coast, particularly in the *pineta* of San Rossore (Pisa). This pine-wood had been artificially created by the Grand Duchy of Tuscany on land reclaimed from the mouths of the river Arno. Although it is not a natural wood, the centuries-old pines are still a beautiful sight. The area was used in the past as a hunting reserve by the Savoia family, and is now open to the public. There were several reasons for the death of such large numbers of pines, but careful examination of their needles indicated that they had been damaged by salt. This was originally believed to be impossible, because pines had grown for centuries along the coast without damage. Among the many hypotheses put forward were lowering of the watertable or infiltration of seawater, but there was no proof of this. The cause was finally attributed to a complex series of factors, the origin of which was excessive use of detergents produced by towns and industry. This area of Tuscany is densely populated and detergents were being discharged into the river Arno and then dispersed in the sea, near the San Rossore *pineta*. Although detergents are not toxic in themselves, in this case, carried in the form of aerosol by wind, some of their components had gradually damaged the cuticle of the pine needles and the protective layer of their stomata, causing aerosol-carried salt to penetrate. Unlike detergents, salt is toxic, and this caused the death of the pines.

In detective novels, murderers are sought after their crime; in this case, the whole population had committed a murder, by using detergents to excess. Natural soap has never had truly noxious effects, but washing machines and dishwashers require large quantities of synthetic products, which slowly dissolve in water and may have unpredictable consequences, like the large-scale destruction of pine-trees. This event provided a timely warning and prompted the creation of purifying systems so that today, the discharge of detergents in water has decreased and the pine-wood is gradually recovering.

Risk due to subsidence. Other significant although little-known risks are associated with extensive subsidence (sinking) of coasts, which occurs when water, natural gas or fuel are pumped from the subsoil nearby. The ecological consequences of this phenomenon (many centimetres per century) are similar to those caused by periodic rises in sea level.

Risk due to pollution of waters (seas, lagoons, rivers) and agriculture. Marine, lagoonal, fluvial and agricultural pollution may affect coastal sandy ecosystems in many ways, according to the type of polluting substances and materials, and to the different ways they reach beaches and dunes. Polluting substances may be divided into:

- **Coarse, solid, inert, non-biodegradable materials** (of usually low specific weight) composed of urban waste, waste discharged from ships, or materials carried down to the sea by rivers during floods and then washed ashore - together with the countless types of rubbish which tourists abandon on beaches. These materials have an immediate “negative impact”, i.e., a miserable sight for visitors to the beach. Notwithstanding the incivility of those who leave inert waste on beaches, or throw it into rivers or from ships, these materials mainly have devastating aesthetic rather than ecological effects on coastal ecosystems. Boxes, plastic bags, cans, bottles and other inert artificial objects are dreadful to look at but, unless they cover surfaces completely, they do not actually affect coastal communities, and are relatively easily removed.
- **Biodegradable substances** may be abandoned by tourists on beaches or thrown in the sea, or represent fertilizers or organic matter carried by rivers or seas but produced by man. These substances severely affect beach-dune systems. Excrement, food residues, and generally biodegradable, non-toxic substances are nutritious for dune substrates and modify their nature, giving rise to local eutrophy, fostering massive invasions by plant and animal species which do not naturally belong to these environments. They may severely damage the local food chains and the natural equilibrium. Nearby towns also produce large quantities of foam, caused by the exaggerated use of detergents, which may also produce eutrophy. All these substances, which dissolve or blend with seawater and then accumulate on beaches, may later have more serious effects, triggering bacterial and algal activity on the beach surface, as weak but deadly “binding materials”, and contributing to the formation of more or less compact surface crusts of sand. Crusting does not allow sun-dried sand to be carried by winds, and this modifies its natural cycle, hinders dune formation, and jeopardizes the self-repair mechanisms of beach-dune systems.

Beaches are environments subject to strong dynamism: for example, violent sea-storm can change beach's aspects within one season (mouth of the Irminio river, southern Sicily)

● **Very fine-grained, inert material**. Run-off by rivers on earthy or earthy-clayey soils eroded by man's intervention often produces large quantities of very fine materials such as silt and clay, which are carried to the mouths of rivers or nearby sandy shores. These materials may also have binding effects on sand and lead to the formation of crusts.

● **Substances carried by marine aerosol or by seaward winds**. The release by seawater of substances which are carried by winds as aerosol may affect plant communities.

In particular, synthetic detergents carried by sea winds have complex, negative effects when combined with salt and other substances, damaging the metabolism of coastal plants (see p. 116). The extensive use of insecticides and herbicides in agriculture severely damages the flora and fauna of nearby dunes and heathland ecosystems.

Lastly, industry and thermo-electric power stations in coastal or sub-coastal areas cause acid rain carried by seaward winds.

● **Fuel oils**. It is well-known that illegal dumping of harmful materials and accidental oil spills are extremely hazardous for marine and terrestrial coastal communities. It is necessary to distinguish between the uncivilized custom of washing out and "cleaning" tanker cisterns in the sea, and the catastrophic consequences of shipwreck or pipeline breakage. In the former case, small

Even beaches where sea turtles lay their eggs in spring are later used by tourists. This inevitably jeopardizes the reproduction of these reptiles (Lampedusa, near Sicily)

quantities of fuel (i.e., its non-volatile, viscous part) accumulate on beaches, usually between the intertidal and eulittoral belts, forming small tarry lumps which only partially damage psammobious animal communities and cause problems to bathers.
In the latter case, the effects are immediate and devastating along extensive stretches of coastline and to entire animal communities, as crude oil reaches the coast and soaks into the plumage of seabirds. The resulting extensive tarry masses are difficult to remove, and solvents may cause even greater damage than the oil itself. Once again, crusting of sand may occur.

Risk due to erosion, quarrying and seaward motion of sand. In the introductory chapters, we described sand-dune systems as governed by the interaction of many factors in dynamic equilibrium, and in this the natural cycle of sand obviously plays a fundamental role.
Erosion is a completely natural phenomenon, as are both the storms which cause it and the cyclic accumulation of sand in nearby sea stretches. Problems arise when exogenous (usually human) interventions modify one of these parameters, even far from the coast.
For instance, as sand is gradually carried to sub-coastal areas and becomes part of consolidated soils covered by vegetation, it is no longer part of the cycle of shore sand, and must be replaced with new material supplied from the sea or rivers.
When nearby rivers supply large quantities of sand, one large dam is sufficient to bar the watercourse and stop the natural supply and accumulation of sand downstream.
Long periods of drought, when catchment basins near sandy coasts are not filled, may cause a similar reduction in sediment supply. Other parameters being equal, those beaches will be subjected to short- or medium-term erosion, until the disturbing factor is removed.
Another important phenomenon is indiscriminate removal of sand for building purposes. If large quantities of sand are excavated, they are removed from their natural cycle, and local erosion will prevail unnaturally over accumulation, threatening nearby beaches and dunes.
But sand-loving animal communities are also severely damaged by the removal of sand, and by the movement and weight of materials and vehicles used to remove it.
However, these are all reversible phenomena if catchment basins are managed carefully, if the climate follows its natural course, and if the removal of sand is locally abolished or controlled.

Risk due to construction of jetties, artificial cliffs or tide barrages. Since Roman times, man has carried out works to modify the natural structure of coasts, especially near river mouths or naturally sheltered bays. Recently, quite large-scale coastal modifications have occurred with the aim of creating new ports and marinas, and for hydraulic engineering works. It is therefore useful to mention a few details regarding the above-mentioned “laws of sandy coasts”:

- If various kinds of rigid barriers (jetties, artificial rubble mounds, etc.) are built between the sea and its beaches, they will inevitably become eroded and disappear, together with their dune systems, or large investments will have to be made to replace them artificially.
- When large stretches of sea are closed with artificial barrages to control tides, particularly near river mouths, this will not only cause water eutrophication, but also crusting of exposed beaches, thus hindering the self-repair processes of dunes and beaches and altering the stability of natural biotic communities.

Another kind of imbalance, unfortunately irreversible unless drastic steps are taken, regards the insufficient quantity of sand carried ashore. Long barrages perpendicular or sub-perpendicular to beaches (i.e., concrete or wooden jetties, metal gabionades, or structures made of other materials) may also alter the coastline. On one hand, their presence will give rise to considerable advance of beaches which are upface with respect to prevailing longshore currents; on the other hand, equyally evident retreat will follow to the lee of beaches following the barriers. In the mid-term any dune systems behind will follow the fate and induced evolutioon of their respective beaches.

It is clear that, although artificial interventions may have a positive effect on beaches which are already influenced by man and have very low naturalistic value (to keep erosion under control or improve beaches for tourist exploitation), they are extremely dangerous if applied to still natural, good-quality beaches.

Risk due to presence of towns, coastal building, dune stabilization, and cultivation of trees and shrubs. Many human activities have recently moved towards the sea, for agricultural, tourist, commercial or industrial reasons. Beaches are often built on for tourist purposes without any planning or control, with destructive results. Beaches have often been totally populated, e.g., in Sicily and Calabria, and houses are often built a few metres from the sea (usually illegally), thus preventing anyone from reaching the beaches - which belong to everybody. Beach flora and fauna have disappeared completely, and camp-sites have invaded dune systems and coastal woodland, especially pine woodland, giving rise to complete loss of complexity of the environment.

Although coastal building does have destructive effects on natural habitats and the surrounding landscape, some of its less obvious positive effects are worth noting. Houses, roads and fields must sometimes be protected against wind, marine aerosol and sand. Walls, palisades, windbreaks, hedges, and rows of trees are therefore placed as obstacles near dunes or even beaches to protect human activities.

Similarly, trees and shrubs may be planted near dunes and beaches, with the presumed aim of consolidating them. However, any significantly high artificial or pseudo-natural element erected transversally between dune heathland and the sea changes the direction of winds, the accumulation cycle of windblown sand, and therefore the self-repair mechanisms of dunes and beaches. Natural environments and their original, dynamic, geological and vegetational balances change, and the entire ecosystem enters a state of crisis. It has been estimated that a windbreak (hedge, house, food kiosk, etc.) may negatively influence the maintenance and natural evolution of a dune system inland up to 30 times the height of the obstacle itself.

Coastal building has often locally altered the height at which winds blow, giving rise to unusual, abnormal sand accumulation in towns because sand displaced from beaches and embryo dunes can no longer interact with shrubby dune vegetation, as it usually does.

Coastal roads are another important problem, especially when they are built

Systems to protect beaches from erosion in upper Adriatic

Century plant, or agave (*Agave americana*)

between beaches and dunes or between wandering and consolidated dunes. Once again, the natural cycle of sand is disturbed, as road maintenance damages nearby natural vegetation (use of herbicides, deforestation, fire) and many alien, euryecious plant species easily colonize dunes and beaches using this extempore pathway, and jeopardize natural vegetation. The consequences for animals are even worse, as large numbers of invertebrates and small vertebrates are killed by cars, particularly at night, because, as we have already seen, their activities and search for food across beach-dune systems are often concentrated during the hours of darkness.

Risk due to introduction of alien species. One of the most important modifications of the biological populations of beach-dune systems is expansion of alien, invasive species. The flora of beach environments is usually highly specialized and does not tolerate the introduction of alien species well. Examples are: *Conyza albida, Cynodon dactylon, Oenothera biennis, Tragus racemosus* and false acacia or black locust. *Cenchrus longispinus* (= *C. tribuloides, C. incertus*), a coastal grass from America, has recently invaded Italian beaches. First discovered in Italy in 1933 on beaches near Venice, it was rare until the 1960s. Then it started to spread, and shortly after invaded Adriatic and Tyrrhenian shores. Its small spiky leaves, which in adult plants are covered by very sharp thorns, are extremely irritating for tourists.

Carpobrotus

Another typical example is *Carpobrotus*, a large, creeping mesembrianthem of south African origin, which is invading many Mediterranean areas (mainly Tyrrhenian coast in Italy), dunes and heathland, partly replacing the original psammophilous vegetation. Century plant (*Agave americana*, Agavaceae), of central-American origin, is a problem on many dune beaches in central-southern Italy - particularly in Sicily and Sardinia - due to its large biomass and high reproductive capacity.

Many Australian and south African tree and shrub species have been extensively used to consolidate dunes and heathland, contributing to the loss of complexity of ecosystems but never solving the erosion against which they had been planted, but rather causing new problems (e.g., coastal reafforestation with *Eucalyptus* may cause reduction in underground freshwater reserves, and the large quantity of bark which collects on the ground prevents the natural evolution of soils).

Risk due to tourism and bathing. We have decided to leave this subject to last, as it probably represents the greatest disturbance for sandy coastal ecosystems, particularly their biotic communities.

All the most specialized and delicate animal and plant species of beaches and dunes are severely threatened by people walking over them - not to mention the passage of vehicles! Most people view these environments as mere recreation areas, without considering their high naturalistic value. The worst damage is caused in spring and summer by the large numbers of people who swarm on to a few square metres of sand, treading on the waterline, its halophilous invertebrate communities and pioneering shrubby vegetation, picking the flowers of the most typical plants, crossing dunes and "fertilizing" them with all sorts of organic waste. Disorderly crossing of dunes gives rise to erosion and contributes to the spread of alien species. But also in winter there may be acts of environmental vandalism, when cross-country drivers venture on to beaches with their 4-wheel-drive cars or huge motorbikes, taking undue advantage of the few people around and the little or total lack of control exerted by local authorities.

Even greater disturbance is caused by mechanized cleaning, modelling and enrichment of beaches and embryo dunes, which destroy forever the local sand-loving invertebrates, their natural shelters (usually stranded debris), and often the associated supralittoral pioneering flora.

Unfortunately, local institutions often promote these operations, which have really devastating effects on coastal ecosystems when caterpillar-tracked vehicles and similar equipment are used.

■ Conservation strategies and operative guidelines

Many possible interventions must be carried out, immediately or in the near future, to protect sandy coastal ecosystems. So far, many beach and dune environments in Italy have remained intact only by sheer chance and, in the days to come, we should not rely on fortune or chance, but commit ourselves to maintaining them in good condition for future generations. This may be done by means of careful planning, so that, where possible, beaches may be extended in the middle term to areas now severely degraded by man's negative influence. Before analysing the naturalistic aspects which justify the need to protect coasts, let us list a series of "rules" for the conservation of large portions of relict sandy beaches in Italy.

First of all, we must distinguish between three types of intervention: those aimed at creating tourist beaches, and those aimed at protecting beaches partially, or totally. In the first and second cases, free access to beaches cannot be denied, provided that people use them properly. An initial problem may be parking: instead of forbidding cars, less good-quality areas could be used as efficient car-parks, in order both to isolate the beach from traffic and to prevent people from parking their cars anywhere and everywhere. Paths with simple wooden handrails could be constructed across dunes, where people cannot stop during the heat of the day. Tourists would then have free access to the

Beach at the mouth of a river after a storm

Sandy littoral in the Salento (Sothern Italy)

beach. However, this model for beach management can only work if people have some sort of environmental information, and a few successful experiments have been carried out in Italy.

As regards sandy beaches which have to be totally protected (the following paragraph describes how to select them), very good-quality areas of at least 1-2 kilometres should be selected and forbidden to the public, in order to make tourists aware of their responsibilities. Pioneering vegetation and the lives of the most delicate sand-loving organisms would be protected from erosion caused by treading, eutrophication, sullying and contaminating of soils, and the introduction of euryecious or alien plant and animal species. In these small areas, selected by scientists:

- Agriculture, roads or houses immediately inland, and vehicles must not be permitted. These measures would restrict the erosion, loss of complexity and impoverishment of coastal environments. There should also be an inland belt of good environmental quality in case the sea level rises or coastal soils sink.
- Mass tourism should be controlled in nearby unprotected areas, forbidding mechanized cleaning of beaches, in order to constitute a sort of floral and faunistic “corridor”.
- Nearby fluvial and marine pollution, and supply of fine debris from excessive run-off upstream should be reduced. These operations would limit severe crusting of sandy shores.

Simple but efficient interventions to keep cars from beaches

- Jetties, artificial barriers and rubble mounds, which modify natural currents and waves, should not be built on nearby coasts. Shrubs and trees should not be planted on dunes to consolidate them or prevent their erosion, nor should any construction hinder winds. This would not modify the natural cycle of sand, dune formation, and the morphological and vegetational self-repair processes of beach-dune systems.
- Alien vegetation on dunes should be gradually and carefully eliminated, starting from the juvenile stages of particularly large plants which have greater vegetative or reproductive capacities, whereas larger, older specimens should be eliminated on the spot with mechanized equipment.

Their remains can be allowed gradually to decay naturally and be replaced by autochthonous vegetation.

But mass destruction, with removal of roots by excavation, may negatively affect the small invertebrates which shelter under alien vegetation.

- Stranded debris could periodically be collected by groups of volunteers supported by experts and environmental associations.

They would have to work manually, not using mechanized vehicles at all, and tarry waste and other matter would have to be taken away directly, without using solvents.

The natural capacities for resilience and diffusion of communities and single species must prompt us to act immediately, in order to protect stretches of relict beaches and sandy dunes of good environmental quality, wherever they are and no matter how small they may be.

As regards conservation biology, it is usually thought to be easier to protect a few large areas instead of many small stretches of beach far apart from each other.

But, as we have seen above, it is in fact better to protect small sandy beaches totally, as long as floral and faunal "corridors" are maintained even in areas visited by tourists: fortunately, sea shores are naturally good ecological "corridors", and are only occasionally completely destroyed by man.

A particularly successful, although not always feasible strategy should also provide for the institution of marine reserves, in order to protect the whole sea-land area. Unfortunately, apart from a few parts of the coastline where turtles typically breed, marine reserves rarely coincide with sandy coastal environments to be protected - in fact, they are generally associated with rocky shores and cliffs.

Lastly, tanker routes should be re-organized in order to keep ships far from shores of good environmental quality, in the all too frequent cases of ship-wreck or partial fuel discharge.

■ Which species and communities must be protected?

The conservation of dune environments and of the biodiversity of beach flora and fauna was recognized by the Habitat Directive of the European Community (Directive 92/43/EC, and its annexes). The plant species and subspecies of Italian beaches, dunes and heathland which officially need to be protected immediately are the following (Annexe II of the Habitat Directive: "Animal and plant species of Community interest whose conservation requires the designation of special areas of conservation"; species with an asterisk are officially considered extremely important):

**Anchusa crispa* (Boraginaceae): sandy dunes and beaches in north-western Sardinia (and Corsica); *Euphrasia marchesettii* (figwort family): damp heathland meadows on the Veneto and Friuli coasts; *Linaria flava* ssp. *sardoa* (figwort family): sandy Sardinian beaches; *Kosteletzkya pentacarpos* (= *Hibiscus pentacarpos*) (mallows): sandy, sub-brackish areas along mid-Tyrrhenian coasts and the Lagoon of Venice (a Pontic component extending to the Black Sea); **Muscari gussonei* (lilies): arid heathland in southern Sicily; *Rouya polygama* (umbellifers): sandy coastal environments in Sardinia (also Corsica and Tunisia); **Stipa veneta* (grasses): arid heathland on Veneto coasts.

Annexe I of the Habitat Directive views the following types of dune and beach environments of the Mediterranean coasts to be of considerable importance:

Gillyflower (*Matthiola sinuata*), a rare crucifer on Tyrrhenian beaches

Consolidated shore dunes covered with *Crucianellion maritimae* vegetation; dunes with *Euphorbia terracina*; dunes with vegetation of the *Malcolmietalia* type; dunes with annual vegetation of the *Brachypodietalia* type; dunes with *Juniperus* spp.; dunes with sclerophyllous vegetation of the *Cisto-Lavanduletalia* type; dunes covered with *Pinus pinea* and/or *Pinus pinaster* woodland; flooded Mediterranean meadows (*Juncetalia maritimi*); halophilous and thermo-Atlantic Mediterranean meadows and scrub (*Sarcocornietea fruticosi*); halonitrophilous meadows and scrub (*Pegano-Salsoletea*).

Various, more or less well distributed plant species which are slowly disappearing from beaches and dunes in Italy are also very interesting and must be protected. Some of the most important are the crucifers *Matthiola sinuata* (gillyflower, a large Mediterranean-Atlantic species found on embryo dunes and near consolidated dunes on Tyrrhenian and Apulian coasts) and the interesting, now relict gymnosperms of the genus *Ephedra*, such as *Ephedra fragilis* and *E. distachya,* both Mediterranean species found in fragmented areas. In Italy, they are found on low dunes of good environmental quality in southern Italy, Sicily and Sardinia. *Matthiola* and *Ephedra* host various species of endemic or sub-endemic phytophagous insects which are extremely interesting from the ecological and biogeographical viewpoints. As regards animal species, there are no typical invertebrate species or subspecies living on beaches, dunes and heathland in Italy listed in the Habitat Directive, due to the lack of any official notification.

The situation of vertebrates is better and, although birds are not listed in Annexe II of the Habitat Directive, the infrequent cliff birds which typically live in sandy environments are mentioned in EEC Directive 79/409: oyster catcher (*Haematopus ostralegus*), Kentish plower (*Charadrius alexandrinus*), ringed plover (*Charadrius hiaticula*), red-backed sandpiper (*Calidris alpina*), sanderling (*Calidris alba*), stone curlew (*Burhinus oedicnemus*) and common pratincole (*Glareola pratincola*).

The Habitat Directive also lists many other bird species typical of the Mediterranean maquis, brackish lagoons and pools, which sometimes, while migrating, visit sandy beaches and hide among reed-beds and rushes.

The only reptile listed in the Habitat Directive, Annexe II, is common sea turtle (*Caretta caretta*), which reproduces on sandy beaches in Sicily and a few areas in southern Italy. Annexe II also contains the relatively euryecious, now infrequent common tortoise (*Testudo hermanni*), which does not rank very high in the list of priority for conservation; similarly for four-lined snake (*Elaphe quatuorlineata*) and leopard snake (*Elaphe situla*), which are occasionally found on sandy shore dunes in southern Italy.

There are many invertebrates which are extremely interesting from the faunistic, biogeographical and ecological viewpoints, and many have been treated in the section devoted to invertebrates. Most of them are endemic or sub-endemic to Italy, found in restricted, fragmented areas, and should be protected both locally (and perhaps are already) and by the European Community.

Psammoardoinellus sardiniensis

Among the many coastal species are the endemic scarabs *Ceratophyus rossii* and *Heptaulacus rasettii* (shore dunes and sub-coastal paleo-dunes in Tuscany), *Paratriodonta romana* (Latium), *Paratriodonta cinctipennis*, *Anoxia ragusai*, *Haplidia massai* and *Hoplia attilioi* (Sicily), *Calicnemis sardiniensis* (Sardinia), *Pachypus candidae* (Tyrrhenian coasts in central-southern Italy), and the relict *Thorectes marginatus* (southern Sicily and western north Africa). Among endemic darkling beetles are *Psammoardoinellus sardiniensis* and *Stenohelops carlofortinus* (southern and western Sardinia), relict pollen beetles endemic to Italy, such as *Meligethes opacus*, *M. varicollis* (western Sardinia and western Mediterranean coasts) and *M*. cfr. *longulus* (Italian coasts and Spain), the rare handsome fungus beetle *Dapsa obscurissima* (occasionally found along the coasts in Tuscany, Latium and northern Tunisia), the endemic weevils *Phoeniconyx gobbii* (Ionian coasts in Basilicata), and *Paroxyonyx* sp. (southern Sicily) and the rare *Ceutorhyncus matthiolae* and *C. pantellarianus* (Italian shores and a few western and central Mediterranean areas). Many other species found in European Mediterranean areas, such as the ground beetles *Eurynebria complanata* and *Cylindera trisignata,* are highly specialized and risk extinction locally. A few endemic members of other families should at least be mentioned, such as the antlike flower beetle *Amblyderus brunneus*, endemic to Calabria and Sicily, a few rove beetles of the genera *Throbalium* and *Remus*, and the rare leaf beetle *Chrysolina schatzmayri*, endemic to the Veneto coastline.

Among lepidopterans is the rare burnet moth *Zygaena orana* (western Sardinia and Algeria) and the widespread, typical owlet moth *Brythis crini*. Among orthopterans, a few endemic species are very important, such as *Dirshius*

uvarovi (found in many Italian areas), *Dociostaurus minutus, Ochrilidia sicula, Pterolepis siciliensis* and *P. elymica* (southern and western Sicily), *Ochrilidia nuragica* and *Pterolepis pedata* (southern Sardinia), *Ephippiger appulus* (Apulia), and the extremely interesting *Roeseliana brunneri* and *Zeuneriana marmorata* (high Adriatic). It is also worth mentioning the beautiful, widespread and very large cricket *Brachytrupes megacephalus* (southern Sicily and Sardinia, northern Africa). Among neuropterans there are a few dune-loving *Creoleon*, like *C. plumbeus* on Adriatic shores, *C. lugdunensis* along the Tyrrhenian, Ionian and low Adriatic, *C. aegyptiacus* in Sicily, *C. corsicus* in Sardinia and the Tuscan Archipelago, and *Megistopus mirabilis*, a south-eastern Mediterranean species found near brackish heathland environments in a few areas in Latium between the Circeo promontory and the Italian president's country residence at Castelporziano.

Among other invertebrates are the rare geophilomorph centipede *Geophilus fucorum* (Sardinia, western Liguria, southern France), the millipede *Thalassisobates litoralis* (Italy and its islands), and a few of the already mentioned endemic isopods of the genera *Porcellio* and *Armadillidium*, the endemic molluscs *Ichnusomunda sacchii* (western Sardinia), *Polloneriella contermina* (Latium and western Sardinia), *Cernuella aradasi* (eastern Sicily) and the relict *Xeromunda durieui* (Ionian Apulia and north Africa).

There are also many other groups of endemic invertebrates which are little known in Italy and are not treated in this volume (e.g., nematodes, oligochaetes, mites, springtails, minor insect orders, etc.).

■ Which areas to protect?

The conservation and natural conditions of Italian coasts vary according to region. This situation affects projects aimed at the conservation of local ecosystems, as they must consider the natural biodiversity of these areas, which is mainly the result of historical and biogeographical factors. Before analysing Italian sandy coasts from the conservationist viewpoint, let us examine the actual situation of coasts in the various Italian regions. The following data are taken from results of the Holofernes Project (*Progetto Oloferne*) of WWF Italy (1996-1997), which took into account various parameters such as differing types of coasts, the quantity of infrastructures and buildings, distances between free or protected areas, etc. Occupation rates vary from almost completely free areas in Sardinia (73.6%) to a minimum of 0% in Abruzzi, with good percentages in Basilicata (54.9%), Tuscany (43.3%), Veneto (40.2%), Emilia Romagna (29.2%) and Friuli Venezia Giulia

Semi-natural Calabrian beach

(25.4%), but there are serious problems in Campania (6.5%), Marches (8.3%) and Molise (4.3%), and figures between 14-18% in the other regions.

The situation is therefore still acceptable in large areas of the central-northern Tyrrhenian, Ionian and high Adriatic regions, and particularly in Sardinia, whereas elsewhere only a few, fragmented stretches of beach are still free, usually surrounded by densely populated beaches.

These data on the occupation of coasts are very useful, since they provide a general but realistic view of the conservation of coasts and some indications on future issues to be solved urgently. However, we must also consider the small beaches of good environmental quality which host endemic, relict (usually animal) organisms which are exclusive to these ecosystems and which are in themselves naturalistic emergencies. Coastal fauna and flora are ecological relict sanctuaries which must be protected at all costs, as now and in the days to come they will be sources of biodiversity from which nearby ecosystems will continually draw elements for their re-colonization.

All the data collected for the publication of this small volume clearly indicate that Italian sandy coasts contains flora and fauna which are highly important from the viewpoints of biodiversity and endemism. Here they are listed according to naturalistic and conservationist importance:

- Southern Sicilian coasts (at least from the provinces of Trapani to Catania)
- Western and southern Sardinian coasts

- Tyrrhenian shores in Tuscany and Latium (at least from Pisa to the Circeo promontory)
- Ionian coasts in Apulia and Basilicata
- High Adriatic coasts

These are the surviving sandy coastal ecosystems which must be protected at all costs, as they contain significant numbers of endemic or relict flora and fauna, with species which cannot be found anywhere else in Italy, Europe - or, indeed, in the world.

■ Environmental rehabilitation and re-qualification

So far, we have dealt with useful methods for improving the conservation of the most interesting sandy coastal biotopes and preventing qualitative degradation of their biotic communities by means of indirect intervention. However, there are also beaches and dunes which have already been severely damaged or completely eroded by human activities in the past, but which may now be reconstructed and re-qualified for naturalistic or tourist reasons, or to protect coastal towns.

The rehabilitation of beach environments is not only an Italian issue, but a global one which is both technically very difficult and very expensive. This problem has been successfully dealt with in other countries such as Spain, France and Holland, but also Australia and the United States. Italian, European and extra-European experience gave good results, especially when all elements were considered and re-qualification aimed at re-creating the original natural conditions of ecosystems. Rehabilitation is best when beaches and dunes are reconstructed to be as similar to their original condition as possible, using only indigenous grassy and shrubby species for phyto-stabilization. Natural beaches and dunes are the result of centuries of remodelling and settlement, a balance between local erosive, depositional and vegetational factors. Nature determines which height, width and orientation are best for dune systems and beaches, and which plant species are best suited to consolidate them if necessary. As we have already seen, one of the laws of sandy coast geomorphology states that no human intervention can restore the natural evolution of a beach-dune system which has been altered by persistent and prolonged disturbance. However, this does not mean that good environmental rehabilitation cannot restore a coastal environment to its natural condition in only a few years if, obviously, disturbances are removed or at least reduced, and if the beach stretch is not too far from other sandy beaches which may be used as natural sources of repopulation. In Italy, methods for the environmental rehabilitation of beach-dune environments have been tested for a few years, by enrichment with large amounts of mostly sea sand, with autochthonous vegetation used for phyto-consolidation.

The most typical operations were carried out in the high Adriatic along the Veneto coastline (Lido del Cavallino, north-east of Venice) in the mid-1990s, to stop the severe erosion of beaches near Venice caused by the prolonged construction of sea-walls by the Venetians in the 18th century and modifications in the Po Delta. The beach of Pellestrina, between Chioggia and Venice, has recently been restored, after it had been completely eroded by the sea. An ancient, post-glacial beach cusp was found 10 m deep offshore; sufficient sand was taken from it to reconstruct the sandy substrate of a new beach.

The works in Pellestrina and Lido di Cavallino were carried out to protect nearby towns from storms, rather than for tourist reasons. Apparently, they have been successful, but only in the future will we know if beaches and dunes can survive in spite of constant erosion, or whether the sea will demolish them again. This experience demonstrates that battles for the environment are never lost, because many solutions are possible and even serious damage can be reversed.

The ideal process for restoring eroded or destroyed dune systems is shown in *Rehabilitation of a beach-dune system: operative sequence* (pp.138-139).

Pathway to a beach

Rehabilitation of beach-dune systems: operative sequence

The following phases are required for proper rehabilitation.

1. The environmental and economic compatibility of the project is evaluated by collecting all available information on the natural status of the site, from the geomorphological viewpoint (photos, drawings, maps, memories of local people, etc.) and the characteristics of its sand. All useful information on potentially natural vegetation and associated invertebrates is collected.

2. The volume of sand needed to enrich the area is calculated, in order to be able to recreate the same original or estimated natural dunes. The structures and final profiles of the whole system are designed. With the supervision of sedimentologists and marine biologists, a suitable area is identified from which enrichment sand may be removed without damaging the coastal morphology and benthic communities. Sea sand is best, and should be excavated from a depth of 10-20 metres, possibly near the enrichment site - for two reasons: because it is similar, and because transport costs can be minimized.

3. Plant species which are suitable for artificial and controlled recolonization of mobile and wandering dunes are identified and, for each species, the number of small plants needed is calculated. Autochthonous plants are best both for stabilization of wandering dunes and the development of many diversified plant species. The guide-species in the phytostabilization of rehabilitating dunes in the Mediterranean is ammophila or marram grass (*Ammophila littoralis*), to be followed later by locally more suitable psammophilous herbs or shrubby species for embryo dunes and heathland (*Lotus* spp., *Cakile maritima*, *Juniperus* spp., *Rosmarinus officinalis*, *Tamarix* spp., *Quercus ilex*, etc.).

4. In nearby areas of good environmental quality, with the authorization of the competent controlling authorities, and in accordance with botanists and zoologists, dune ecosystems are identified from which species can be taken for replanting, adopting local thinning-out techniques. Usually, for each species, not more than 5-10% of the total number of plants required are collected, and the original plant community must be highly resilient. Local nurseries providing small plants and their seeds may often represent a valuable alternative or a useful complement.

5. The sand required for the new dune system is dredged and immediately unloaded in its new position near the exposed beach. The new dunes are partially modelled with mechanized vehicles, allowing time for waves, tide and winds to complete the remaining work.

6. The area where new plant species are to be planted are prepared by emplacing branches, artificial netting, etc. in squares and parallel lines, partially buried in the dunes, and adding woody windbreaks to protect the delicate initial phase during which the newly introduced plants must take root and start to grow again.

7. With the help of skilled agricultural workers, plants are collected and quickly replanted in their new site. Initially, planting should provide for mean optimal clumps of 5-6 plants of *Ammophila* per square metre, arranging smaller areas of about a dozen square metres with about 15 plants per square metre and alternating them with large, empty, or little colonized areas. This arrangement is very similar to that of natural *Ammophila* clumps and enables the spontaneous or induced colonization of other pioneering species. Scattering dunes with the stranded remains of *Posidonia* and other sea grasses also yields good results, as they are natural materials available on the spot which naturally disappear and do not require maintenance.

8. *Ammophila* is integrated with other plants and the area is monitored periodically for 2-3 years to check plant growth (transplanting survival rate) and ecosystem resilience (transplanting naturalness), i.e., the capacity of other pioneering plants to take root spontaneously on artificially reconstructed dunes.

9. Psammophilous invertebrate communities which have spontaneously colonized the area for at least 3 years are also monitored. Of particular interest are beetles, which colonize and scatter rapidly. This makes them excellent biomarkers (i.e., they provide indications on the biological quality of terrestrial ecosystems).

A Biotic Index, which adopts objective, repetitive and comparative tools, has recently been devised to calculate the numbers of beetles on shore dunes in Italy efficiently. It derives from qualitative evaluation which has long been carried out on macrobenthic communities in running waters.

It has already been successfully experimented for local monitoring of dunes near Gioia Tauro (Calabria) and the Circeo National Park (Latium).

Dune colonized by tamarisk, ephedra and restharrow (Sicily)

Suggestions for teaching

MARGHERITA SOLARI

There are few environments like those of natural beaches and dunes which receive so little respect from visitors who are not interested in nature and do not want to tread on shells and stranded algae, but who prefer rows of beach umbrellas and comfort.
New generations must be educated to adopt a responsible approach, to preserve these environments: any form of teaching is therefore useful in promoting their knowledge and respect.
The following suggestions propose itineraries for children of various ages and provide ideas for teachers and educators.

■ Organisms and their traces

- Objectives: to enhance pupils' capacities for observation, analysis and hypothesis: to promote their knowledge of an environment characterized by peculiar flora and fauna; to make them aware of the richness of natural environments like beaches.
- Level: primary school (5-10 years of age).
- Equipment: suitable clothing, and spare clothes for the excursion. Camera, notebook, bags for collecting material.
- Possible collaborators: guides or expert naturalists.

PRELIMINARY STAGE

1. Class discussion and possible excursion, to analyse the shape and structure of grasses, shrubs, trees, soils and animal species.

BEACH EXCURSION

2. Group excursion to a beach which should be in a natural condition, not "cleaned" of stranded material.
3. Observation of the beach environment: initially children can do this alone or in small groups.
4. Observation by means of guided discussions of various beach components: soil and sand, wet or dry, more or less compact; observation of plants:

In spite of the dry environment, even mushrooms can colonize beaches

Footprints of wild rabbit and lizard

Footprints of roe deer

Footprints of badger

size and shape of stalks and leaves (in order to compare them with known meadow grasses), thorns (if any), and depth of roots.

5. Observation of animals (although this is often difficult): among vertebrates, only birds are usually visible (seagulls, whereas other typical visitors such as Kentish plovers, curlew sandpipers and passerines are difficult to identify).

Great attention is needed for invertebrates, although a few *Cicindela* or *Pimelia* may sometimes be seen near stranded algae and debris, and large scarabs or the frantic activity of sphecid hymenopterans may be observed. It is easier to look for traces of organisms on sand (footprints, excrement, dens) and make guesses about which animals could be found nearby.

6. Collect stranded material along the waterline, between land and sea: find out the nature and origin of the material. There may be grasses and sea algae the structure of which can be analysed, or the remains of terrestrial vertebrates or stranded fish, crustaceans, molluscs, jellyfish, etc., useful for initial, simple animal classification, to be examined in greater detail in class. Shells and collected remains must be thoroughly washed, treated, and perfectly dried, for their best preservation.

7. Make hypotheses on the origin of occasional stranded debris.

8. Identify the high-tide line and the storm line.

CONCLUSION OF WORK (IN CLASS)

9. Discuss the impressions offered by this environment, and examine the differences with tourist beaches, if children are familiar with them.

10. Discuss the importance of conservation.

■ Study of dune beaches

- Objectives: to promote capacity for analysis and comparison of environmental parameters; to identify cause-effect relationships in the study of the environment; to create awareness of the complexity and variety of beach and dune environments; to promote the need to preserve them by identifying the delicate balances which determine their development.
- Level: secondary school pupils (14 and over).
- Equipment: suitable clothing, high boots, compass, wind-vane, probe or graduated ruler, sieves of various mesh-size.

PRELIMINARY STAGE

1. Introduce to the class beach and dune environments and the phenomena which govern their morphology and evolution (winds, waves, vegetation, etc.).

2. Identify a good, natural beach containing dunes and heathland.

3. Estimate the distance between this beach and the nearest estuary (or estuaries) using a map. Identify the direction of currents on nautical maps or from computerized information.

4. Define parameters for observations and organize them properly in written form.

EXCURSION

5. Measure the various areas of the beach: approximate gradient of the submerged section (with boots and graduated ruler; measurements must be taken at fixed distances from the shore, e.g., every metre); length and approximate gradient of intertidal and exposed beaches (draw their profiles); identify ordinary and storm berms, bars and troughs.

6. Analyse the particle sizes of sand (generally between 2 and 0.03 mm), colour, and larger granules (pebbles, etc.).

7. Identify stranded material, its nature and origin.

8. Measure wind direction with respect to compass north.

9. Measure the distances of dunes with respect to the coastline, calculate their height and direction (traverse or parabolic) with regard to the coastline, winds, and compass north.

10. Take notes on the type of vegetation and species contained in the first dunes. Observe their extensive root apparatus, and the density of the sand.
11. Use the same parameters on the consolidated dunes behind: compare sand density, vegetal cover, plant morphology and species.
12. Use the same parameters for interdunal hollows and coastal woodland nearby.

CONCLISION OF WORK

13. Analyse data and discuss the peculiarities of this environment, the great importance of preserving it, and the need to stop uncivilized exploitation of coasts.
14. Make hypotheses on the evolution of the environment, its dynamics, the factors which affect its morphology, and the influence of human activities.

NOTES

If possible, measurements should be repeated in summer and winter, noting the differences.

■ Adaptation observed in beach vegetation

- Objectives: to enhance capacity for observation, analysis and comparison; to understand the complex adaptations of plants to their environment; to make children aware of the interactions between vegetation and morphology.
- Level: elementary and secondary school children, organized into various levels for children aged 11-16.
- Equipment: suitable clothing, handbook for identification of plants, bags for collecting specimens.

PRELIMINARY STAGE

1. Discuss the limitations of beaches: permeable sandy substrates which do not hold rainwater, brackish watertable, presence of salt in aerosol, pollutants in aerosol, winter and summer temperatures, etc.
2. Focus on the scarcity of freshwater in sandy soils and the high transpiration of plants in warm climates; study the peculiar adaptations of plants to arid environments. Organize research work on several bibliographic sources.
3. Make out a check-list for use during the excursion, in order to determine and describe which and how many adaptations are observed in plants in that environment.

Example of such a list:
- Succulence
- Hairiness
- Coriaceous leaves
- Rhizomes creeping under sand
- Annuality (after correct identification).

EXCURSION

4. Choose a beach with dunes the vegetation of which is suited to your observations.
5. Discuss observations on the spot, in groups or as a single group, and identify plant characteristics. Note the differences (e.g., in species found in interdunal hollows).

CONCLUSION OF WORK

6. Analyse data and discuss observations.
7. Write a final report and compare observations and results.

Dune with *Eryngium* and footprints of insects

Select bibliography

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A brief but interesting work on the main animal species associated with Italian coastal environments, by a well-known zoologist, recently deceased. The work belongs to a completely new issue of the volume on the fauna of Italy by the Touring Club Italiano of 1959.

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An enjoyable work (divided into environments, including waterlines and dunes) on insects found on coasts in Latium, with many photos and colourful illustrations.

MINELLI A., RUFFO S., LA POSTA S. (eds.), 1993-1995 - Checklist delle specie della fauna italiana. 110 fascicoli (“*Checklist of Italian faunal species. 110 volumes*”). *Edagricole,* Bologna.
A reference point for the identification of the updated name (and author’s name) of all Italian animal species, with general indications on their geographic distribution in Italy.

PIETROBELLI M., BARDI S., 1996 - Le aree libere costiere (“*The free littoral areas*”). Risultati del progetto WWF Italia “OLOFERNE”, Crociera 1996, Volume I. Documento 48, *WWF Italia,* Rome.
Current state of occupation of land along Italy littoral environment.

PIETROBELLI M. (ed.), 1998 - La Progettazione ambientale nei sistemi costieri (“*Environmental design of coasts*”). *International Association for Environmental Design,* Rome, vol. 12.
An interesting and updated collection of articles regarding environmental management, study and rehabilitation of Italian coastal ecosystems.

PIGNATTI S., 1994 - Ecologia del Paesaggio ("*Landscape ecology*"). UTET, Turin.
An interesting work on the Italian landscape, particularly vegetation. It also contains sections devoted to the conservation of the environment and its cultural aspects.

SPAGNESI M., ZAMBOTTI L., 2001 - Raccolta delle norme nazionali e internazionali per la conservazione della fauna selvatica e degli habitat ("*National and international regulations for the conservation of wild fauna and its habitats*"). Quaderni di Conservazione della Natura, 1, *Ministero dell'Ambiente, Istituto Nazionale Fauna Selvatica,* Ozzano Emilia.
A very useful collection of laws for the conservation of Italian wild fauna, in force in Italy, the European Community and internationally, together with a list of the most interesting Italian sites from the naturalistic viewpoint.

Glossary

> Allopatric: the typical non-overlapping geographical distribution of two or more similar plant or animal species.
> Anthophagous: more or less specialized organisms - usually insects – the larvae or adults of which feed on angiosperm flower parts (corollas, stamens, nectar, etc.).
> Circadian: activities which are carried out over a period of about 24 hours.
> Euryecious: widely distributed organisms which tolerate great variations in the many environments in which they may live.
> Euryzonal: organisms which live and reproduce in various types of environments found at differing gradients (altitude, climate, depth, etc.).
> Hygrophilous: more or less specialized organisms usually associated with damp environments.
> Halobiont: an organisms which is strictly adapted to environments rich in dissolved or crystallized salt (mainly sodium chloride) in soils, usually found near sea shores or coastal brackish lagoons.
> Halophilous: an organism living in environments rich in dissolved or crystallized salt (mainly sodium chloride) in soils, usually found near sea shores or coastal brackish lagoons.
> Isobath: an imaginary line in the sea, lake or river section, which joins all points at the same depth.
> Mesophilous: an organism normally associated with relatively damp, cool environments.
> Microphagous: an organism which exclusively or mainly feeds on micro-organisms such as bacteria, unicellular algae, etc.
> Necrophagous: a more or less specialized organism which exclusively feed on carrion.
> Polytypic: an organism which also occurs in one or more differing subspecies, geographical races or biological forms in their geographic range.
> Pre-imaginal: all larval, immature stages preceding adult insects.
> Pronotum (pl. pronota): the dorsal plate of an insect's prothorax.
> Prothorax: anterior segment of an insect's thorax.
> Psammo-halobious: an organism exclusively adapted to sandy environments rich in dissolved or crystallized salt (mainly sodium chloride) in soils, usually found near sea shores or coastal brackish lagoons.
> Psammo-halophilous: an organism which preferably lives in sandy environments rich in dissolved or crystallized salt (mainly sodium chloride) in soils.
> Psammo-hygrophilous: an organism which preferably lives in damp, sandy environments.
> Psammophilous: an organism living in sandy environments.
> Rhizophagous: more or less specialized organism which feeds on plant roots.
> Saprophagous: more or less specialized organism which exclusively feeds on decaying organic matter.
> Synanthropic: an organism which usually lives in environments or buildings influenced by man's presence.
> Syzygy: noun associated with lunar cycles (new and full moon) and corresponding high and low tides.
> Stenoecious: an organism living in restricted, specialized ecological niches.
> Thermophilous: an organism living in environments with high mean annual temperatures.
> Thermo-hygrophilous: an organism living in damp environments, particularly in areas with high mean annual temperatures.
> Trophic: concerning food and nutrition.
> Xerophilous: an organism which lives in arid, dry habitats.
> Xero-thermophilous: an organism which typically lives in usually arid environments with high mean annual temperatures.
> Zoosaprophagous: more or less specialized organism which feeds exclusively on carrion.

List of species

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Useful and updated information may also be obtained from many Internet sites, including:
Ministero dell'Ambiente e della Tutela del Territorio: www. minambiente.it
Fauna Europaea: www.faunaeur.org
Atlas Florae Europaeae: www.fmnh.helsinki.fi
WWF Italia: www.wwf.it
Seafriends: www.seafriends.org.nz

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