Effects of the 1991 oil spill on the supratidal fringe

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Abstract: The upper littoral fringe is the section of the intertidal that was most severely affected by the 1991 oil spill; it is covered by a continuous layer of tar and oiled sediments. Regular visits at 10 permanent transect lines and other localities within the study area revealed that the strandline lost most of its characteristic biota; in spring 1993 there was still no sign of recovery, except on the steep exposed beaches of Abu Ali Island. The strandline communities of non-oiled control sites were studied and major ecological successions and their key/indicator species identified for future monitoring. Recovery of oiled strandlines can only be expected after habitat restoration by artificial cleaning.

INTRODUCTION

The oil that was released during the spill in the wake of the Gulf War reached the study area north of Jubail in February 1991. While most of the subtidal and lower intertidal habitats escaped visible oil contamination, the upper intertidal and especially the upper littoral fringe including salt-marshes were severely affected, losing most of their characteristic biota (Kinzelbach et al. 1992, Krupp & Jones 1993). Situated at the edge of the terrestrial and the marine ecosystems, this transition zone normally exhibits an increased biodiversity as compared to the upper intertidal and the adjoining terrestrial habitats; this is most evident in arid regions with a comparatively poor though specialised terrestrial fauna. Interactions (e.g. on the trophic level) between these two realms are highly complex and not yet fully understood. Even basic information on the taxonomy and the bionomics of species living in or sporadically frequenting the littoral fringe is fragmentary or missing. Therefore a more complex approach, dealing with the typology of the supralittoral and taking into account synecological aspects, such as food chains and energy flow, will be published at a later date. In the following, emphasis is placed on some of the key species of the communities inhabiting the strandline and on the damage caused by the oil spill.
Topography of the upper littoral: The most striking feature of the coast is its extremely low relief. There is an average slope of only 35 cm per kilometre along the eastern shores of the Arabian landmass. The highest coastal elevation in the survey area is Jabal Saduwi (to the west of the inner end of Dawhat al-Musallamiya) at 34 m above sea level. The rest of the coastline is shaped over its entire length by a beach terrace which corresponds to higher Holocene sea levels (PURSER 1973). As a rule, this platform rises only little (0.3-1.0 m) above the highest tide mark. The sea reaches this level only during spring tides or floods.

Most beaches in the Jubail Marine Wildlife Sanctuary are of the low-energy type, preceded by a shallow tidal flat which protects them from wave action. Usually the stranded material is dispersed over the entire tidal flat and consequently only little debris of marine origin is accumulated in front of the beach terrace; PTLs 5 and 6 (PTL: Permanent Transect Lines) are typical examples. Meandering tidal channels with bordering mangrove stands are special semi-terrestrial habitats within the intertidal zone (e.g. at PTL 2).

About 190 out of 460 km of shore (including al-Batina and Abu Ali Islands) are exposed, high-energy sandy beaches. Their morphology (Fig 1) is very similar to exposed beaches elsewhere, although their slope is less steep and there are tidal flats in front of them. Between the storm berm and the latest berm there is a series of strandlines; after heavy weather old and new material is deposited near the storm berm (e.g. PTLs 5 and 9). It is in this type of "accumulative strandline" that, due to the edge effect, a high species diversity is found.

MATERIAL AND METHODS

In order to assess the damage caused by the oil spill all PTLs (see JONES & RICHMOND 1992) and some newly established control sites were visited and sampled on a regular basis in January 1992, in May/June 1992, in December/January 1992/93, and in March/April 1993. Temperature measurements, in the form of local and/or circadian profiles were taken. Standard methods and devices such as insect nets and sieves of various sizes, Berlese traps, light traps (both white and black light), and UV-lamps were used for collecting.

RESULTS

Strandline as habitat: The strandline is an accumulation of allochthonous debris washed ashore by the surf. In the Project area it consists mainly of marine plants and their epibionts mixed with dead marine animals. The plant debris of exposed beaches is characterised by the predominance of two species, either the brown alga Sargassum binderi (Phaeophyta) or the seagrass Halodule uninervis (Cymodoceaceae); the two are rarely mixed, their occurrence depending on the subtidal substratum (hard or soft bottoms) and the prevailing currents. Material of terrestrial origin (e.g. leaves, pollen, dead arthro-
pods) is of minor importance; it is blown by wind to the open sea and then transported to the beach. In some places, as along the northerly exposed coast of Abu Ali, the strandline is transformed into a trashline by the predominance of waste material (e.g. glass, plastics, tins, plywood).

Besides its important role as a food resource, the strandline provides shelter in a generally harsh environment. The surface temperatures of dry beach sand may well exceed 70 °C in summer (BASSON et al. 1977), but even temperatures around 50 °C are lethal to most intertidal organisms. Phaleria prolix (Coleoptera: Tenebrionidae) collected at the beach and exposed to the sun at normal temperatures (42 °C) on beach sand died within minutes. Due to evaporation of retained moisture, temperatures drop dramatically below the strandline and therefore reduce the environmental stress for organisms living there.

Sargassum-strandlines show a high species diversity as they retain moisture for a very long period and are rich in interstitial crevices, offering a variety of microclimates and microhabitats. While surface temperatures of a Sargassum-strandline ranged between 27 and 49 °C from 9.00 a.m. to 11.00 p.m., those within the plant mass varied only between 31 and 39 °C (Fig. 2).

In contrast, Halodule-strandlines are very poor in species composition; they consist of densely packed, fast-drying flat leaves which leave no space for ventilation, thus preventing evaporative cooling. At PTL 5 the temperature within a seagrass-strandline was 47.7 °C (13.VI.1992; 10.00 a.m.) compared to 37.5 °C in a Sargassum-strandline under similar conditions (Fig. 2).

Although as far as food and the temperature regime are concerned, the strandline seems to offer stable conditions, but it is unstable in other regards.

The status (e.g. size, extent, position) of the strandline at any given time is a function of the balance between the same forces that are responsible for the removal or deposition of sand - the tides. In general the tidal cycle in the Gulf is semi-diurnal (fide JONES 1986) but its effect on the strandline is not predictable; the tidal range is strongly influenced by such factors as topography and the strength and direction of the winds, resulting in a constantly shifting beach morphology. Therefore a major problem for supratidal animals is to maintain populations at proper tidal levels in order to prevent prolonged submergence or prolonged loss of food and cover.

Strandline communities: As pointed out in the introduction, many species take advantage of the food accumulation and shelter provided by the strandline; most of them are adventitious visitors, but for some this is their normal habitat, where they spend their entire life cycle.

Being a habitat of extreme environmental conditions, the littoral fringe is in some respects very similar to desert habitats (e.g. in the lack of easily accessible freshwater and drastic temperature changes). It is therefore not surprising that the majority of coastal arthropods such as Coleoptera, Isopoda and Chelicerata are specialised members of otherwise typically terrestrial families. These are successful under arid conditions and therefore preadapted to colonise the strandline.

Once the seaweed is washed ashore, the ageing strandline goes through a number of successional stages with characteristic primary consumers. The first species to be found are thalorchestid amphipods. Talorchestia aff. martensi was the dominant species at the surveyed sites, the taxonomy of which remains unresolved. A second species, Orchestia platensis, has been reported from Kuwait (JONES 1986). Provided the strandline's debris keeps wet (e.g. through renewed tidal submergence), the amphipods propagate, exceeding the other community members in both biomass and number of individuals. At the same time coelopid seaweed flies appear (Diptera: Brachycera: Coelo-pidae) which complete their entire life cycle under the wrack-beds (DOBSON 1976). Although they propagate to astronomic numbers in a very short time, their distribution along the beach is more patchy. As the seaweed is washed further upshore and is no longer reached by every high tide, it becomes dryer. This next successional state is characterised by the predominance of darkling beetles (Tenebrionidae) and isopods. Three species of

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Fig. 2: Circadian temperature profile of a Sargassum-strandline on a sandy beach near Jubail (27°05'N 49°35'E, 22.VI.1992).
tenebrionid beetles, *Diphyrrhynchus dilatipennis* (Fig. 3), *Phaleria prolixa* (Fig. 4) (SCHAWALLER 1991, 1993) and *Trachyscelis tenuestriatus* (Fig. 5) are found throughout the year. They occur exclusively under seaweed debris, just within the reach of the highest tides on exposed sandy beaches in association with the terrestrial isopod *Tylos maindroni* (for taxonomy see TAITI & FERRARA 1991). All feed on decaying algae, but as observations show, at least larvae and adults of *P. prolixa* are facultative saprophagous scavengers. On beaches with shingle or rocky sections the jigiid isopod *Ligia pigmentata* is found (clean-up site near PTL 4 and tip of Abu Ali; I. Watt and M. Apel, pers. comm.); species of the genus *Littorophiloscia* can be expected to occur there as well (TAITI & FERRARA 1991).

The tenebrionids and *Tylos maindroni* spend their entire life cycle below the strandline. *Trachyscelis tenuestriatus* and *P. prolixa* were found to hibernate as larvae (different instars) and as adults buried in the sand. Whether they are active at a lower level or overwinter in a state of quiescence or diapause is to be investigated. Pupae have so far not been found but are expected to occur in the same habitat. Newly hatched *Trachyscelis tenuestriatus* were found in the sand below the seaweed at depths of 10 cm.

All these organisms are negatively phototactic, with their main activity period starting just before or after sunset. When exposed to light or otherwise disturbed, they remain for seconds in a state of thanatosis and then start digging themselves into the sand. The darkling beetles make use of their specialised clypeal ridge and the enlarged shovel-like tibiae (Figs 3-5). As they are restricted to the strandlines that are closest to the beach berm, permanent submergence by incoming tides is avoided. Nevertheless occasional submergence by spring tides or during storms is tolerated by both larvae and adults as observations in winter 1992/93 and spring 1993 show.

PARDI (1955, 1958) has demonstrated that the Mediterranean species *Phaleria provincialis* is able to orientate itself along a line perpendicular to its native shore; referring (diurnally) to the sun azimuth it maintains a correct angle of orientation. The direction of movement depends on the animals' physiological condition: specimens that are dehydrated and starved (below an old dry strandline) will move towards the sea and are most likely to find a fresh strandline; others, e.g. after having been submerged, will direct themselves inland. *Tylos latreilli* and *Talorchestia deshayesii* exhibit the same behaviour.
(PARDI 1954, PARDI & GRASSI 1955), and we may assume that this also holds true for the species occurring in the Gulf, including *D. dilatipennis* and *T. tenuestriatus*.

The three tenebrionids were found on all offshore islands visited by us (Karan, Jana and Juraid), indicating that they have effective means of dispersal. *Phaleria prolixa* and *D. dilatipennis* were observed swarming in the dark along the beach and may well reach the islands by active dispersal. In contrast *T. tenuestriatus* has rudimentary hindwings; as with isopods and amphipods it depends on other means of transport, e.g. flotsam or "step by step" dispersal.

**Damage by the oil spill**: The recent oil spill polluted all of ca. 400 km coastline in the Jubail Wildlife Sanctuary. Most of the oil is found on tidal flats in the upper reaches of low-energy beaches and in accumulative strandlines along high-energy beaches. Even more than two years after the oil spill these areas are still covered by a nearly continuous layer of oiled sand and solid tar, between 0.5 and 400 m wide. In the supralittoral fringe, penetration depth of oil ranges between 2 and 15 cm. While the tar is now being eroded on the rocky shores and at the water's edge on exposed beaches, there is no visible sign of oil/tar degradation in the sand near the beach berm. In most cases the oiled strandline is located at the highest tide mark, now topped with fresh seaweeds. However, this layer, being separated and sealed from the underlying clean substratum by oil, is almost sterile and devoid of higher life. As a consequence, the fresh plant material is drying rather than being decomposed.

**DISCUSSION**

In the above we have focused on species that spend their entire life cycle within the strandline; they constantly move between the seaweed and the underlying sand, leaving this microhabitat only for dispersal movements or in search of a new wrack-bed when conditions in the old one deteriorate. Some authors (e.g. DOYEN 1976) consider them as "marginally marine", but the terms "strictly coastal" or "strictly littoral" seem to be more appropriate. They form the core of the strandline community, all other visitors depending more or less on them. As presence or absence of these key species reflects the condition of the strandline, they may serve as indicator species.

While they were found at all non-oiled control sites, key strandline species were still absent in spring 1993 at all PTLs visited, except on steep exposed beaches (e.g. along the northern coast of Abu Ali). Here higher tides and a wind-enforced surf established a new and active strandline on clean sand above the uninhabited oiled stripe. As the sandy substratum is not sealed by tar, the habitat of the primary consumers (debris feeders) of the strandline community, the thin layer between the decomposing algal material and the humid sand, is preserved. This clearly demonstrates the potential for recolonisation by recruitment from non-polluted areas outside or from small non-polluted nuclei within the Sanctuary. Although the reclamation of lost territory is favoured by the fact that most organisms of the tidal fringe are r-strategists (producing more offspring than the environment would sustain under undisturbed conditions), recovery can only be expected after the restoration of the strandline habitats by artificial cleaning. Recolonisation will be fast in species with active dispersal, e.g. by swarming flights in *Diphyrrhynchus dilatipennis* and *Phaleria prolixa*, but much slower in species depending on passive transport such as *Trachyscelis tenuestriatus*, amphipod and isopod species.

**REFERENCES**


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