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Dynamics of Litter Pollution on Israeli Mediterranean Beaches: a Budgetary, Litter Flux Approach

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ABSTRACT

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The dynamic behavior of coastal litter is followed on Israeli beaches. Subsequently, the impact of the coastal geomorphology on litter dynamics is examined. Six prototype sampling beaches of different morphology were selected. The position, number, composition and nature of all the litter pieces, within a 50 m beach front, were recorded on each beach. Strips of litter concentration were demarcated and their movement was mapped along shore-normal transects. All items were tagged *in situ,* each beach strip by a different color. These sampling procedures enabled to define inflow, outflow, transfer, storage and reemergence of buried litter. We also calculated the litter budget at each site, traced litter movement through the beach and calculated the residence time and the turnover period. The littered area in all beaches, over the entire study period, was less than one percent. The widest beaches were the most littered. Specific beach morphology, as ridge and runnel, made the backshore an efficient trap for the litter. The results show that the narrower the beach the higher its litter flux. The narrowest sandy beach showed the highest range of dynamics. The litter is spread and organized in distinct strips. Their pattern reflects the specific beach depositional dynamics. The Israeli Mediterranean coast is homogeneous in its high mobility of litter, shown by a similar input and output of litter items and by the almost balanced budget of litter on each studied site. Turnover time, i.e., the time needed to replace the total litter on each beach, is only a few months long and less than half a year. This high mobility of the litter means poor persistence and a good self-cleaning capacity. The data suggests that the Israeli beaches are essentially a transfer route for the litter, which migrates along and finally seems to bypass them.

ADDITIONAL INDEX WORDS: *Beach pollution, beach morphology, Israeli beaches, Mediterranean beaches.*

INTRODUCTION

The Mediterranean coastline of Israel extends for 180 km from the Gaza Strip to the Lebanese border (Figure 1). The Israeli Mediterranean coast is relatively smooth, Haifa bay being the only irregularity. The beaches of central and northern Israel are usually narrow, from a few tenth of meters up to a maximum width of 100–200 meters and are almost completely sandy. Eolianite is located intermittently along the coast forming low ridges. Long segments of eolianite coastal cliff, up to 40 m high, back the beach.

The Israeli beaches consist of medium sand, originating mainly from the Nile and its submarine delta. Haifa bay is the northern border of the quartz province of the Nile. The southern coast consists of medium to fine quartz sand beaches; whereas, towards the north, the coastline becomes rocky with pocket beaches. Well-sorted medium beach sand decrease in size from Egypt eastwards (EMERY and NEEV, 1960). Beachrock occurs along the waterline. The surf zone is narrow, usually a few tenth of meters. The nearshore shelf, up to 30m depth, is of low slope gradient—0.5–1.0 degrees. Its bathymetry is basically uncomplicated, parallel and simple (GOLDSMITH and GOLIK, 1980).

Wave breaking is predominantly in the spilling range. The microtidal range is less than 50 cm. The mean significant wave height ranges from 1.1 m during winter to 0.5 m during spring and autumn, and tidal range is about 30 cm. Wave climate during the study period (Figure 2) showed the typical Mediterranean seasonality with an intermediate summer swell wave regime from May to November with 35–45% of the waves between 0.5–1.0 m, followed by winter storms of 2–4 m significant wave heights from December to March. Maximum wave conditions occur when a large low pressure system lingers in the Aegean Sea. The passage of the storm fronts and change in barometric pressure ensure that low wave conditions return within a few days. These wave data are representative of the entire Mediterranean coastal segment from the south to Haifa Bay (ROSEN and VAKDA, 1979; GOLDSMITH and GOLIK, 1980).

An east-northward net longshore current domains the cell from the Nile delta to Haifa. Because of change in shoreline orientation the net longshore transport becomes increasingly

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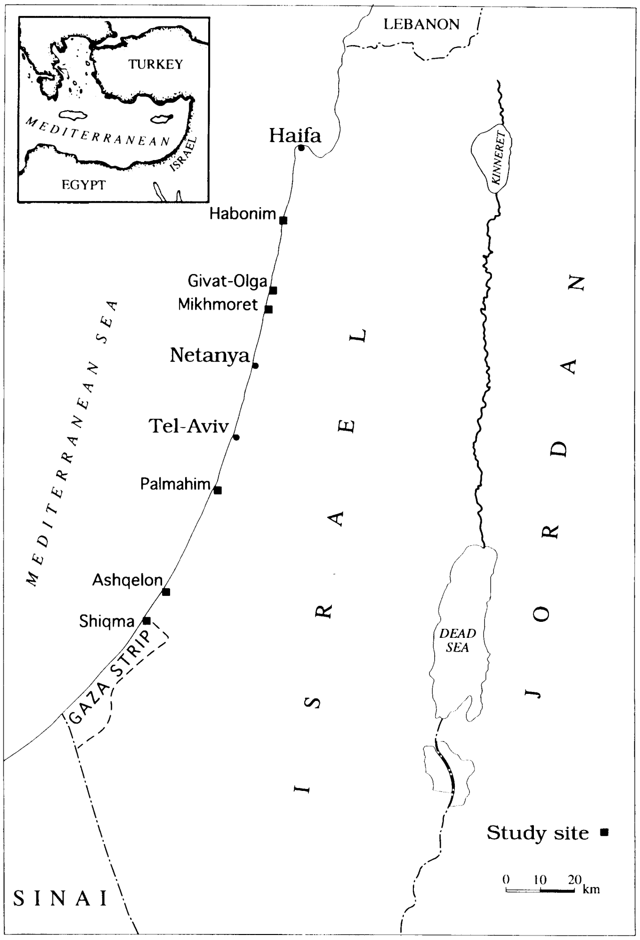

Figure 1. Location of the study sites between Haifa and the Gaza Strip.

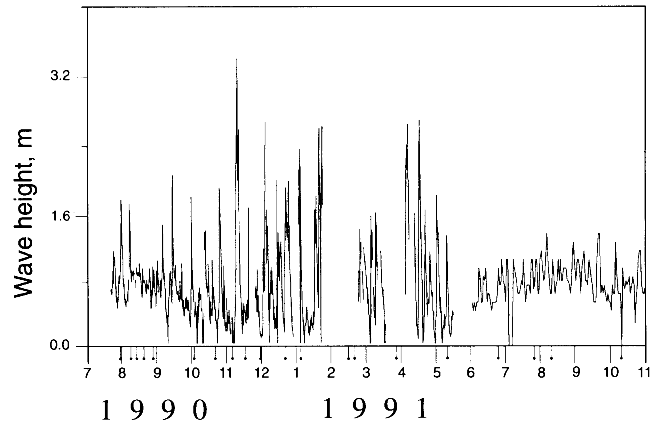

Figure 2. The history of the characteristic wave height measured in the deep water off Hadera, by Givat-Olga, during the study period. The period 7.90–5.91 was calculated by D. Rosen following Komar (1977). The period 6.91–10.91 is based on Titelman (1992). The data were prepared on a common base by D. Rosen, Israel Oceanographic and Limnological Research, Haifa. The months are indicated by numbers and the dots show the days of litter sampling.

smaller from south to north. The longshore current between the Gaza strip and Haifa is believed to converge near Netanya (EMERY and NEEV, 1960; GOLIK, 1993), controlled by changes in the wave approach direction.

The Mediterranean beaches of Israel are an important national tourist resource because they are sandy, enjoy plenty of sunshine the year through and are easily accessible. Coastal garbage, tar balls and oil pollution have, however, a negative aesthetic impact which can become detrimental to the tourism industry as well as to the local recreational activity.

Coastal garbage along the northern Israeli coast was studied by GOLIK and GERTNER (1992) who showed that the litter quantities on the beach fluctuate seasonally and proposed that most of the litter is land-based. GABRIELIDES *et al.* (1991) reported the results of comparative studies on behaviour of coastal litter in several Mediterranean countries. The distance of beaches from population centers was found to be the main controlling factor of land-based litter. SHIBER (1979) and SHIBER and BARRALES-RIENDA (1991) studied the distribution of litter on the beaches of Beirut, Lebanon. A review of studies on the litter in the Mediterranean was prepared by GOLIK (in press). Most previous studies worldwide dealt with quantities and with the type of the garbage, but only a few (TSOUK *et al.*, 1985; ANITA, 1993) took a course towards litter dynamics and budget calculations of entering and bypassing litter, which are of great importance to those who try to mitigate the problem.

The purpose of this study is to evaluate the quantity of litter on the Israeli beaches, to determine its type, density and pattern of distribution, to evaluate the rate of inflow and outflow of the litter as well as its residence time on the beaches. The results should indicate the impact of coastal geomorphology on the self-cleaning capacity and on the dynamics of the litter.

SAMPLING SITES

Six beaches were selected for sampling along the Mediterranean coast of Israel from the Gaza Strip to Haifa Bay (Figure 1). Their characteristics are given in Table 1. All beaches were sandy except Givat-Olga which is mainly gravelly. The beaches range from very narrow (Givat-Olga), narrow (Mikhmoret) to medium-narrow (Ashqelon), all with a coastal cliff. The very wide beaches (Palmahim and Shiqma) have no coastal cliff. Habonim is an eolianite, rocky beach. Public beaches were not included in the study, nor were sites where cleanup operations had been undertaken. However, all sites were visited mainly at weekends by bathers and beach-goers. Palmahim beach is an exception; it is closed to the public and serves in our study as a control site which is free of human effects.

METHODS

Field Sampling

Field data were collected between July 1990 and October 1991 usually at monthly intervals. During some months bi-

Table 1. *Main morphological characteristics and litter components.*

Site	Beach Width m	Wood %	Plastic %	Characteristics
Habonim	—	14	73	Abrasional platform, eolianite bedrock, no beach
Givat-Olga	12	6	88	Gravelly beach, cliff
Mikhmoret	23	7	84	Sandy beach, cliff
Palmahim	120	46	39	Sandy beach, ridge & runnel
Ashqelon	50	11	81	Sandy beach, cliff
Shiqma	150	4	85	Sandy beach

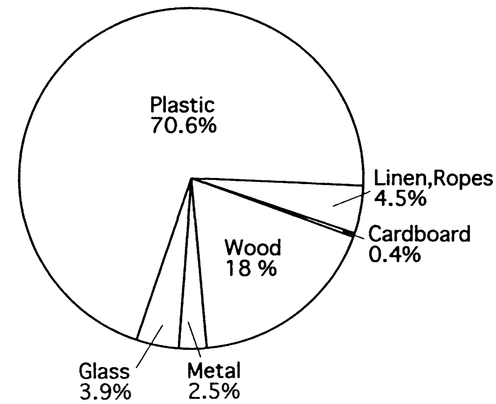

Figure 3. Mean composition of the litter at all sites for the entire study period. Plastic constitutes the main component of litter.

weekly sampling was undertaken. In August 1990 field sampling was carried out at weekly intervals. We bear in mind that the different time intervals between sampling contributed towards increased fluctuations of those indexes which were based on accumulative data. This, however, does not seem to change the main trends.

At each study site a 50 m beach front was demarcated by stakes. As litter is deposited on the beaches in elongated, shore-parallel strips, the pattern of the strips is a fingerprint of litter dynamics. We recorded the magnitude, location and migration of each strip of litter. All the litter items found in one strip were painted in the same color. Each strip got a different color. On each following field survey all unpainted items were recorded as input litter.

All visible litter pieces, within the demarcated 50 m beach front, were counted and their composition—plastic, metal, glass, paper, wood, cloth *etc.*, and type—bags, containers, bottles *etc.*—were recorded. The natural conditions were not disturbed by the field work, *i.e.,* the litter items were neither removed nor collected but spray painted *in situ.* Samples of 30 pieces of each litter type were measured for defining their surface area as an index of environmental spoil. Counting litter pieces poses the problem of ignoring their different sizes, specific densities and forms which make them of different hydraulic equivalence. However, except Palmahim, the composition of the litter in all the study sites seems to be quite similar (Table 1). Conclusions based on comparisons of the number of litter pieces will, however, be drawn only if there is a very clear difference.

The levels of weathering and of burial of the litter items in the sand were defined by four categories. The burial categories were: fully exposed, initially buried, half buried and almost completely buried. The states of weathering were : unweathered items with fresh original colour and fresh edges; items initially blurred with fairly worn edges; very blurred, pitted, broken, disjointed or rusted items and disintegrated items in the form of very blurred, disjointed and rusted small pieces. Fifty cm deep pits were dug in the dirtiest strip in each site for examining whether the litter starts to accumulate below the surface.

Data Processing

All information on each litter item—date of observation, material, type, strip location, stage of weathering and of burial—was stored. Based on the field records the following data files were formed: (**A**) The total number of litter items on each of the sampled beaches. This is a general magnitude, disregarding the width of the beach, the magnitude of each litter item and its environmental impact. (**B**) The number of litter pieces within each of the beach strips. (**C**) The number of the unpainted, input litter items into each sampled beach. (**D**) The number of items which were lost in each study site since the last counting, derived by the total number of items encountered on the beach in the previous visit minus the painted items recovered in the following visit. (**E**) The density of the litter on the beach in terms of litter pieces per 100 m^2. (**F**) Litter composition in terms of material: metal, glass, plastic, wood, cardboard, linen and rope. (**G**) The pattern of the litter strips on each beach during the study period. (**H**) The litter dynamic index, computed as the number of incoming items (C) plus the number of lost items (D) divided by the number of items which remained on the beach between the two successive visits. (**I**) The density of the litter in terms of its aerial coverage. This was derived by measuring the surface area of a sample of 30 items of each litter type and multiplying its mean surface area by the number of items of the respective type on each beach. The aerial density was computed as the percentage of the beach area.

The sampling procedures enabled us to calculate the litter budget at each site by defining inputs, transfers, storages, reemergence of buried litter, outputs and the turnover time.

RESULTS

Composition

The litter items were sorted into six categories : Plastics including drinking bottles, sheets, containers and boxes; glass, mainly bottles; metals, mainly boxes; and a group which included driftwood, ropes and nets. Figure 3 shows the mean composition of the litter in all the sampled beaches. It can be seen that plastic items constitute most of the litter—70%. The main plastic items are the sheets. Driftwood was found all over the investigated beaches. It is the second litter component in abundance. Palmahim shows an unique composition with 46% wood component, which is very high compared to the other sites (Table 1). The wood was probably dumped by ships passing towards Ashdod Port.

Foreign litter, imported by the sea, was determined by the labels on the items. It included only items which are neither produced nor available in Israel. Part of this litter group originates in countries which have no commercial relations with Israel. The source countries, in order of abundance, are Lebanon, Turkey, Cyprus, Egypt, Jordan, Greece, Italy, Portugal, Saudi Arabia, Philippines, Singapore and the USA. The Lebanese litter sources results from the civil chaos and lack of regulatory enforcement in the country which cause accumulation of vast quantities of litter on its beaches (SHIBER and BARRALES-RIENDA, 1991), part of which drifts southwards towards Israel. The maximum of foreign littering occurs in summer, during the seasonal accumulation.

Quantity and Seasonal Fluctuations of the Litter

Palmahim beach stands out as the most littered beach (Figure 4) with a maximum of 1700 pcs/50m. The second most littered beach, although only about half of Palmahim, is Shiqma with 970 pcs/50m. The least littered site was Mikhmoret with a maximum of 40 pcs/50m. Litter accumulated mainly from July on and during the autumn, with the maximum in November (Figure 4). Such seasonal behaviour is clear at Shiqma, Ashqelon and Givat-Olga beaches. The gradual summer accumulation of litter becomes even clearer when shown in weekly intervals (Figure 5).

Mikhmoret, the narrowest sandy beach and Habonim, which is the only rocky beachless site studied, also follow some seasonal behaviour. Only in Palmahim does the litter not exhibit seasonal fluctuations, possibly because of the trapping effect imposed by its ridge and runnel morphology.

When examining the seasonality of the rate of litter input to the beaches (Figure 6), we may differentiate between the unvisited beaches of Shiqma, Palmahim and Givat-Olga which are typified by an almost constant rate of litter input the year through, and busy beaches, such as Mikhmoret and Ashqelon, which show some seasonal fluctuations, in form of a higher litter input during the summer.

Seasonality of the litter budget, *i.e.,* input minus output of litter, is positive during summer and negative in winter in Shiqma, Ashqelon, Mikhmoret and Givat-Olga (Figure 7).

Density

Previous work (MERRELL, 1980, 1984; WILLOUGHBY, 1986; PRUTER, 1987 and CORBIN and SINGH, 1993) suggested a pollution density index which was considered low (<1.0 item per 1 m beach front), a medium pollution density range (1.0 to 10 items per 1 m beach front) and a high pollution density index (10–100 items per 1 m beach front). This very wide range expresses the diversity in the levels of the beach pollution worldwide while disregarding their different width. Using this index, all the studied sites along the Israeli coast would reach during summer-autumn a "very polluted" state with a pollution density level of up to 35 items per 1 m beach front. During winter all the beaches would become "medium polluted".

The most polluted beach is Palmahim ranging from 21–35 items per 1 m beach front throughout the year. The Israeli beaches are typical Mediterranean beaches with pollution density in the range of 1–100 items per 1 meter of beach front (GOLIK, 1994).

Density was also calculated as the number of litter pieces per 100 m^2 of beach area. This density index indicates that the investigated Israeli beaches range from a minimum of 3–5 up to 13–32 pieces per 100 m^2 of beach area. Givat Olga beach is an exception with 88 pieces per 100 m^2.

The surface area covered by litter ranges from a few m^2 to 28 m^2 per beach. When given as a percentage of the beach area (Figure 8) the surface area covered by litter is less than one percent over the entire study period.

Dynamics

Dynamics have different meanings in studies on beach litter. GARRITY and LEVINGS (1993) examined dynamics by the longevity of the litter on the beach and by the net change of the litter on cleared beaches, thus expressing the variability in litter abundance over time. In our study the dynamic level of the litter is expressed by the quantity of the litter which passed through the beach, *i.e.,* the input and output of the litter between two sampling dates relative to the litter which remained on the beach during that period. Accordingly, the litter dynamic index is the litter in move expressed as a percentage of the litter which settled on the beach. It is a surrogate for the self-cleaning capacity.

Our data shows that the litter dynamic indices are low during the summer and higher in winter when a relatively larger part of the litter is swept off (Figure 9). The mean annual dynamic index of a wide beach such as Shiqma is low—31%. Ashqelon shows high dynamics (>80%) throughout some months of the year with periods of >100% dynamics, meaning that more material is in movement than deposited on the beach. The mean annual dynamic index is here more than double that of Shiqma—77%. The unique very low dynamics (<40%) of Palmahim reflects its depositional character. Its mean annual dynamic index is the lowest encountered–13%—reflecting its great width and well-developed ridge and runnel morphology which effectively protects the backshore, where most of the litter is trapped. The narrowest sandy beach—Mikhmoret—shows the highest mean annual dynamic index of 147%. Swash activity was observed here during summer across the entire beach up to the base of the cliff. In Mikhmoret the beach functions as an active foreshore the year through. Givat-Olga, although narrower, is composed of gravel, which is an efficient buffer against swash activity. This seems to explain why the mean annual dynamic index in such a narrow beach does not range higher than 46%. There is no doubt that the fallen eolianite blocks in the inshore also contribute here towards beach protection. The magnitude of litter input (Figure 6) is quite stable throughout the year in the less visited sites (Shiqma, Palmahim, Givat-Olga and Habonim).

The level of burial can be used as a surrogate of dynamics. The narrow, and rocky beaches—Mikhmoret, Givat-Olga and Habonim—show a very high frequency (72–78%) of the lowest

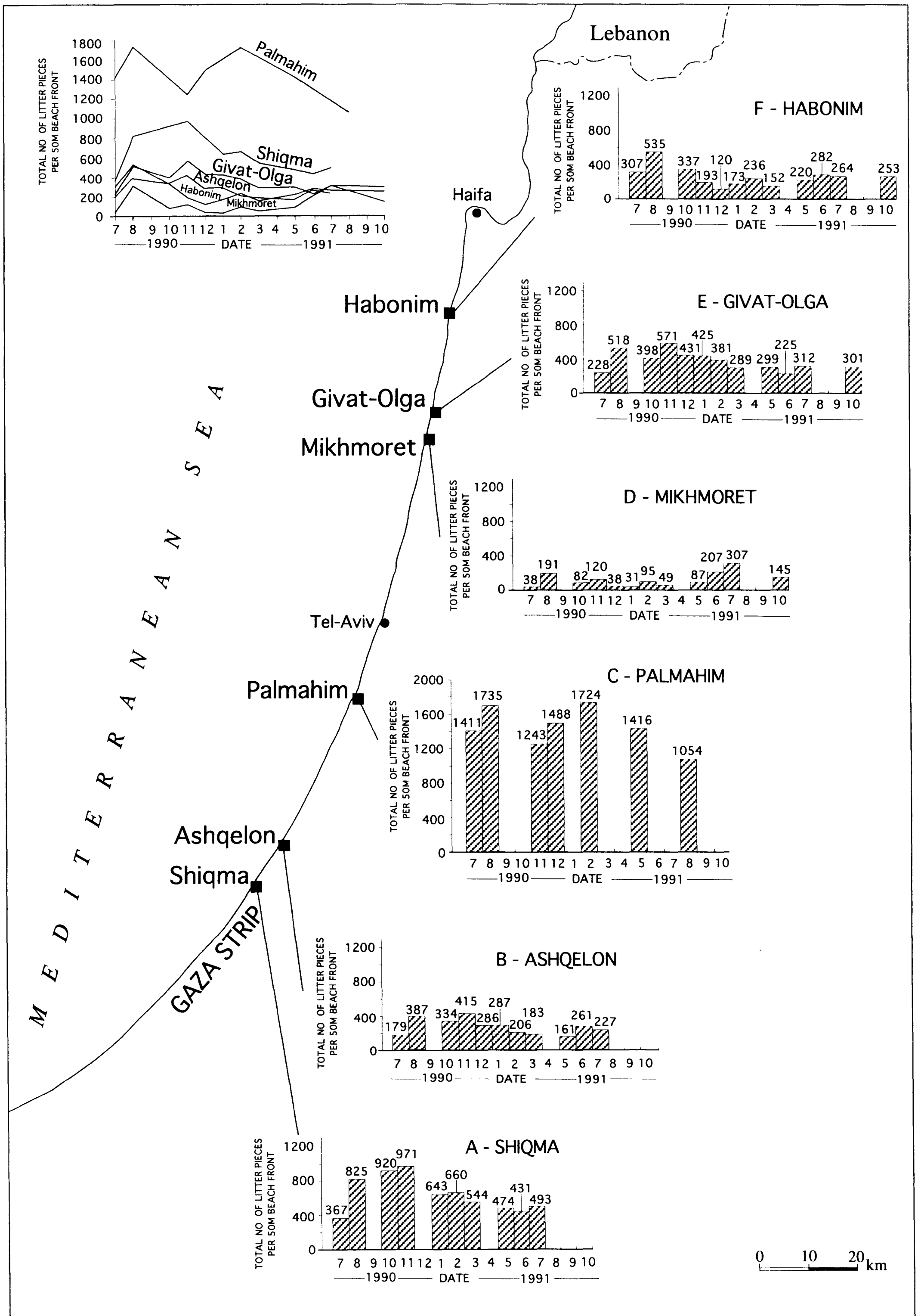

Figure 4. Magnitude of littering at all sites during the study period. Months are indicated by numbers. Palmahim beach is the dirtiest. Shiqma is the second dirtiest. Both are the widest beaches. Mikhmoret beach is the cleanest. Givat-Olga is the narrowest beach but not the cleanest one.

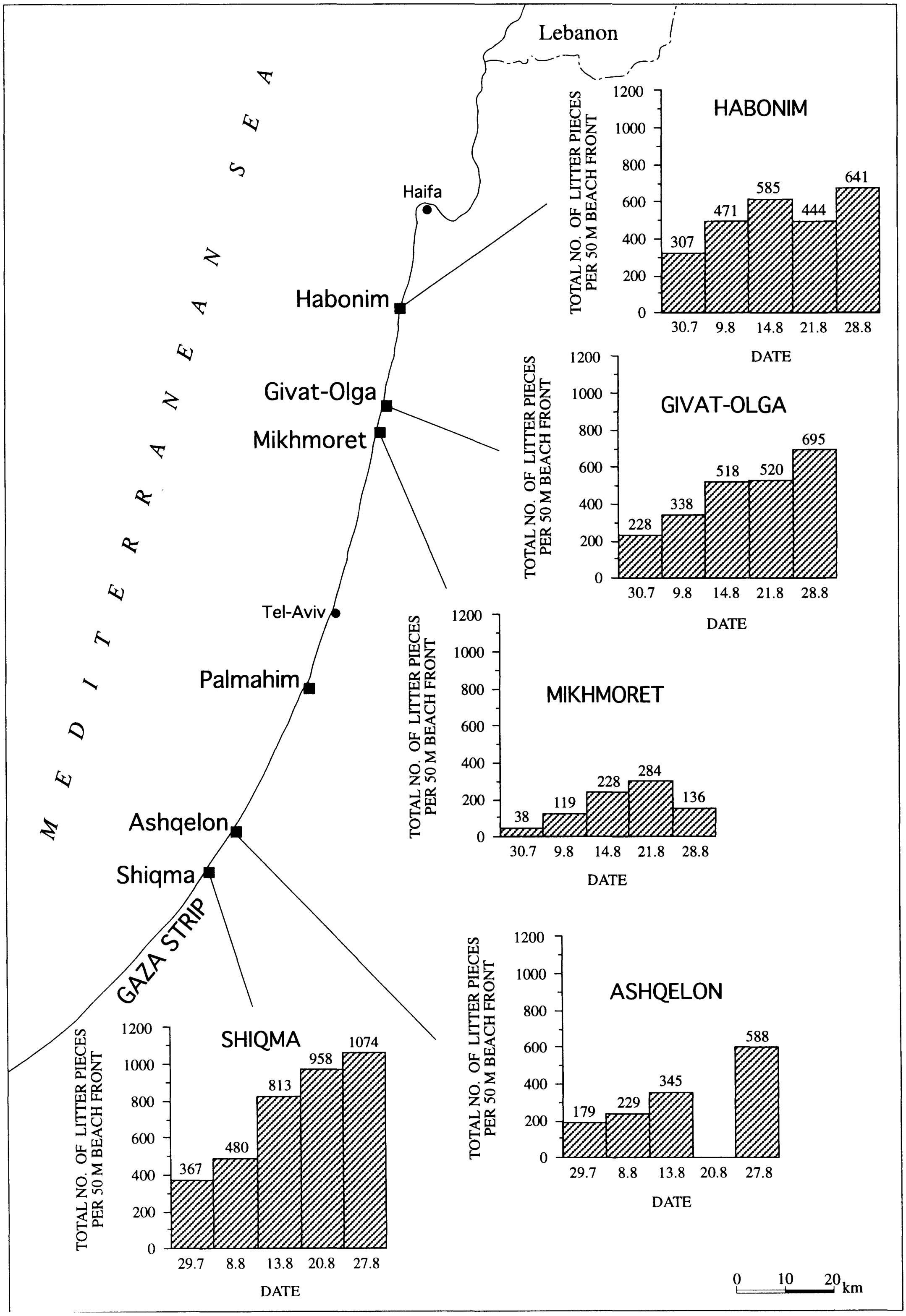

Figure 5. Gradual accumulation of litter during August 1990, shown in weekly intervals. Note the similar overall trend at all the beaches reflecting the summer sand accumulation along the entire Israeli Mediterranean beaches.

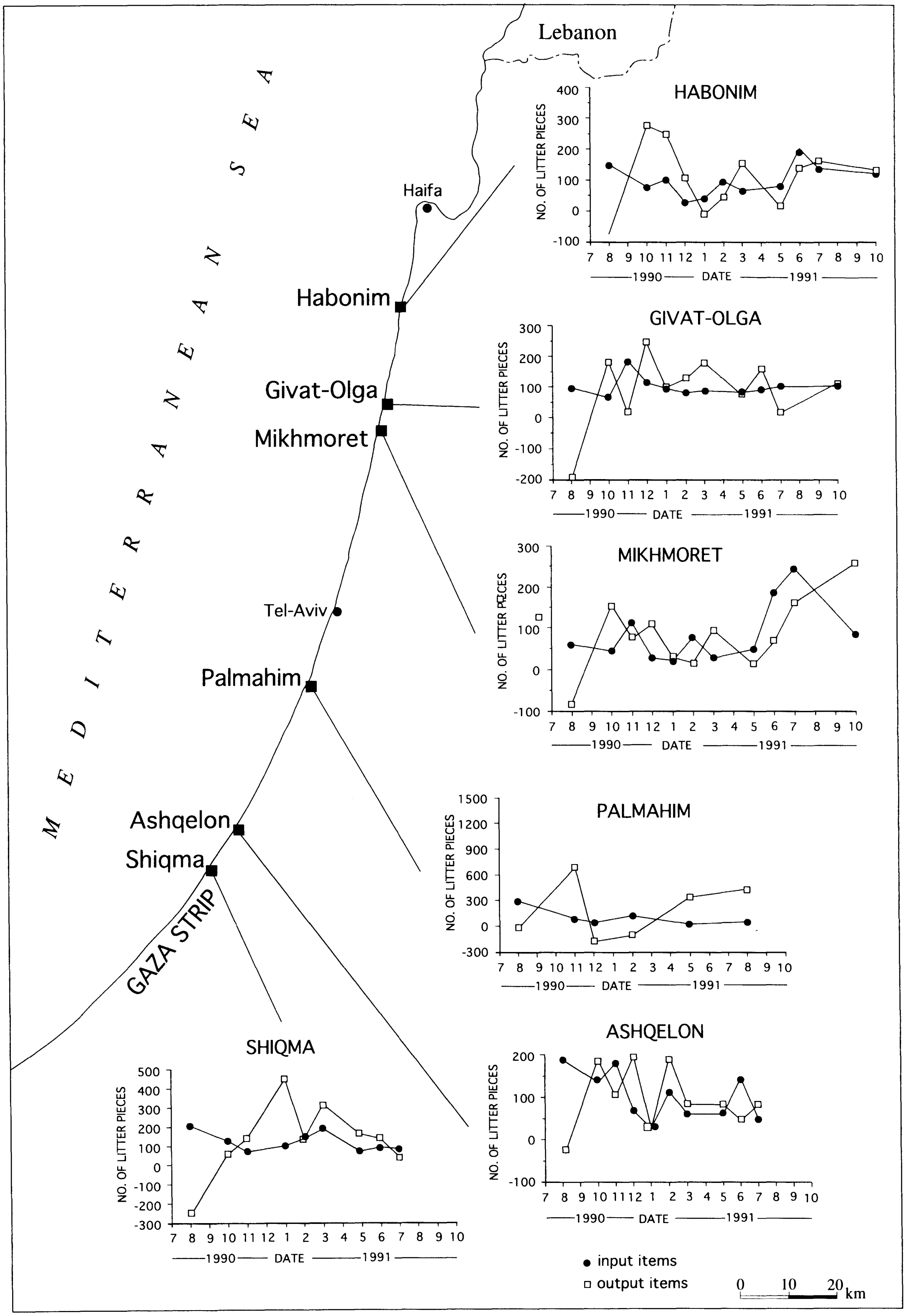

Figure 6. Input and output of litter on the beaches during the study period. Months are indicated by numbers. The beaches of Shiqma, Palmahim and Givat-Olga show a constant rate of litter input throughout the year. Mikhmoret beach shows a higher litter input during summer. Shiqma beach shows a higher rate of litter output during winter.

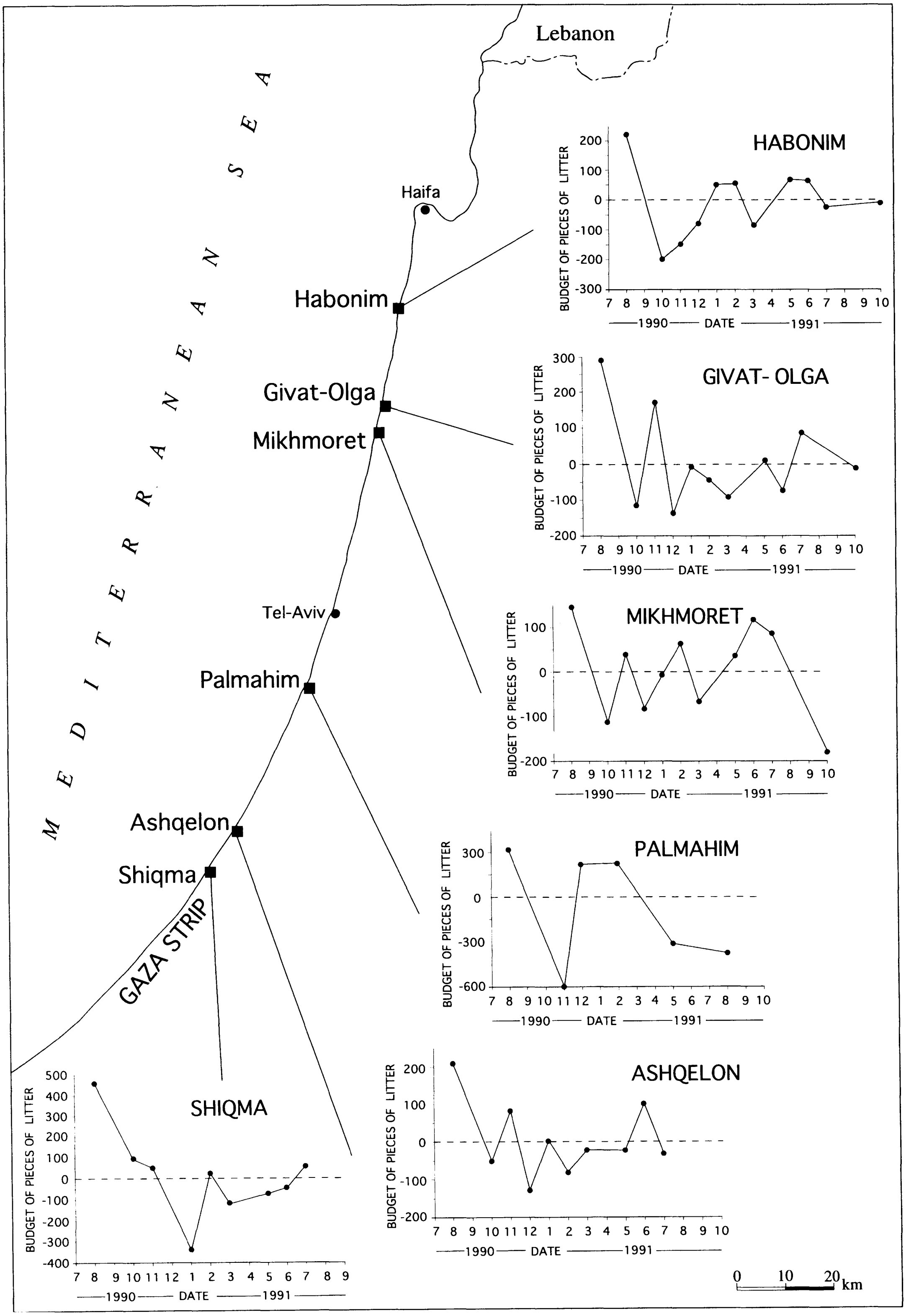

Figure 7. Fluctuations of the litter budget (input minus output). Months are indicated by numbers. Negative budget is typical during the winter wave climate. Positive budget typifies the calmer summer season. The fluctuating curves reflect storms and calms within the seasonal pattern.

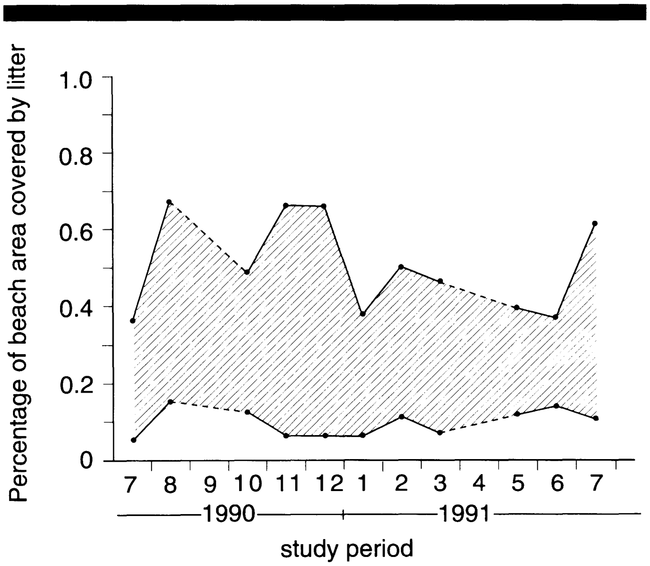

Figure 8. Envelope showing maximum and minimum percentage of the surface beach area covered by litter at all sites during the study period. Months are indicated by numbers. Litter coverage at all sites during the study period is less than one percent.

burial state, reflecting high dynamics. Wide beaches—Shiqma and Palmahim—show only half (34–35%) of that. Ashqelon, a medium wide beach, fits well into the burial model (54%). The highest rate of burial fits these trends nicely, *i.e.,* they are very low in the narrow beaches including Ashqelon and higher in the wider beaches.

No buried litter was observed in all the trenches dug into the most polluted strip, even not in Palmahim. Similar observations were reported by TSOUK *et al.* (1985), *i.e.,* buried tar was relatively uncommon. Weathering did not prove to be an indicator of dynamics.

Patterns of Litter Strips

On medium and wide beaches the litter is spread and organized in distinct strips. Their pattern reflects the specific beach depositional dynamics. The following strip characteristics have been observed:

Strip 1 reflects the regular swash activity on the foreshore. Its width often strongly fluctuates seasonally (Figure 10, Shiqma, Ashqelon). On a well-developed ridge, strip1 is stable the year through (Palmahim). In narrow beaches (Mikhmoret) neither seasonality nor stability of strip 1 were observed.

Strip 1 functions mainly as a transfer zone with relatively little deposition of litter. On wide beaches (Figure 11—Shiqma and Palmahim) only 6–8% of the total litter was concentrated in strip 1. In narrow beaches (Figure 11—Ashqelon, Mikhmoret) where the transfer of litter towards the backshore is limited, 22–46% of the litter was found on the foreshore. On rock-defended beaches with an abrasional plateau, strip 1 becomes the major littered band, with 57% of the total litter.

Strip 2 is located beyond the foreshore and is relatively clean (Figure 11), with only 3–4% of the total litter. In the very narrow Mikhmoret beach it comprised 13% of the total litter. On a well-developed beach ridge morphology (Palmahim) it comprised the upper ridge surface and the backshore. Strip 2 is not invaded regularly by swash activity. However, during storms it is easily crossed and its litter is transferred further backwards.

Strip 3 is the most littered one (Figure 11) with 28–60% of the total litter. It indicates the upper penetration limit of the run up during the typical storms. In Palmahim, the stable ridge drains the litter towards the runnel, where a very narrow—only 4 m wide—densely littered strip 3 is formed. Such runnel is a very efficient trap against backwashing, making strip 3 the most densely littered strip encountered in the study.

Strip 4 is of very different character on different beaches. On wide beaches strip 4 is an intermediate strip between the two most littered ones, *i.e.,* strips 3 and 5 (Figure 11—Shiqma). In Palmahim it is the farthest, eolian-dominated strip, including 19% of the litter. Strips 2 and 4 are transfer strips.

Strip 5 is the widest strip and the second most littered (Figure 11—Shiqma). It indicates maximum penetration of the strongest storms and comprises 47% of the entire beach litter. Strips 3 and 5 thus indicate the penetrations of the low-and high-energy storms, respectively, concentrating 75% of the total litter. If limited by a coastal cliff, strip 5 becomes cleaner, supposedly because of a stronger backwash activity (Figure 11—Ashqelon). Using the farthest litter strip as a marker of the maximum penetration of the run-up across the Israeli beaches (strip 4 in Palmahim and 5 in Shiqma—Figure 11), we conclude that a zone of 90–100 m from the waterline should be regarded as a minimum safety distance for all building and development purposes.

The farthest strips—no. 6 in Shiqma and no. 5 in Ashqelon-are wind-dominated and include 8–11% of the litter. No linear organization of litter, which characterizes the swash-dominated strips, is found here. In the narrowest gravelly beach of Givat-Olga no differentiation in strips could be resolved.

SUMMARY

On most of the beaches of the Mediterranean plastic is the most common type of litter as it is world wide (DIXON and DIXON, 1981; GABRIELIDES *et al.,* 1991; GILLIGAN *et al.,* 1992; LECKE-MITCHELL and MULLIN, 1992; LUCAS, 1992; CORBIN and SINGH, 1993; GARRITY and LEVINGS, 1993; GOLIK, 1994) and Israel is no exception.

The wide beaches—Shiqma and Palmahim—are the most littered and show the lowest rate of dynamics. On the narrow beaches—Ashqelon and Mikhmoret—the magnitude of litter drops dramatically, the rate of mobility increases and seasonality becomes masked; although a seasonal budget can still be traced.

Mikhmoret is the narrowest sandy beach. Although quite heavily visited, it stands out as the cleanest beach, with 2.3 pieces of litter per 1 m of beach front. Shiqma and Palmahim are extremely littered: 12.6 and 28.8 pieces per 1 m beach front, respectively. For comparison: the magnitude of litter found by GOLIK and GERTNER (1992) on beaches in northern Israel, *i.e.,* Tel-Aviv to the Lebanon border, was 5.8—9.1 piec-

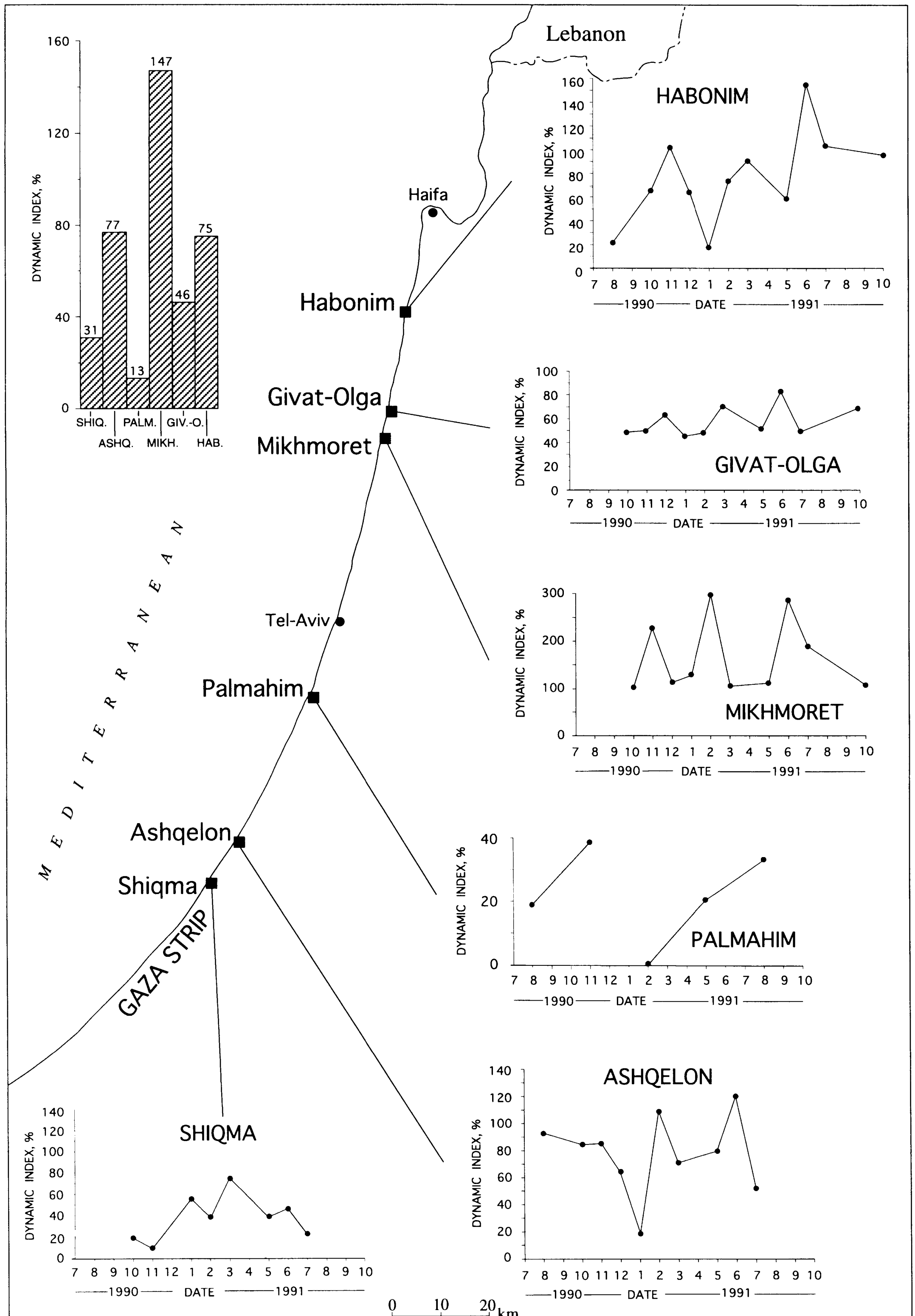

Figure 9. Fluctuations of the litter dynamic index during the study period. Each index of dynamics refers to a period between two consecutive samplings dates and is shown at the end of that period. Months are indicated by numbers. Shiqma beach shows the clearest seasonal trend with the highest dynamic rates in winter. Palmahim beach shows the lowest dynamic index whereas Mikhmoret beach shows very high rates.

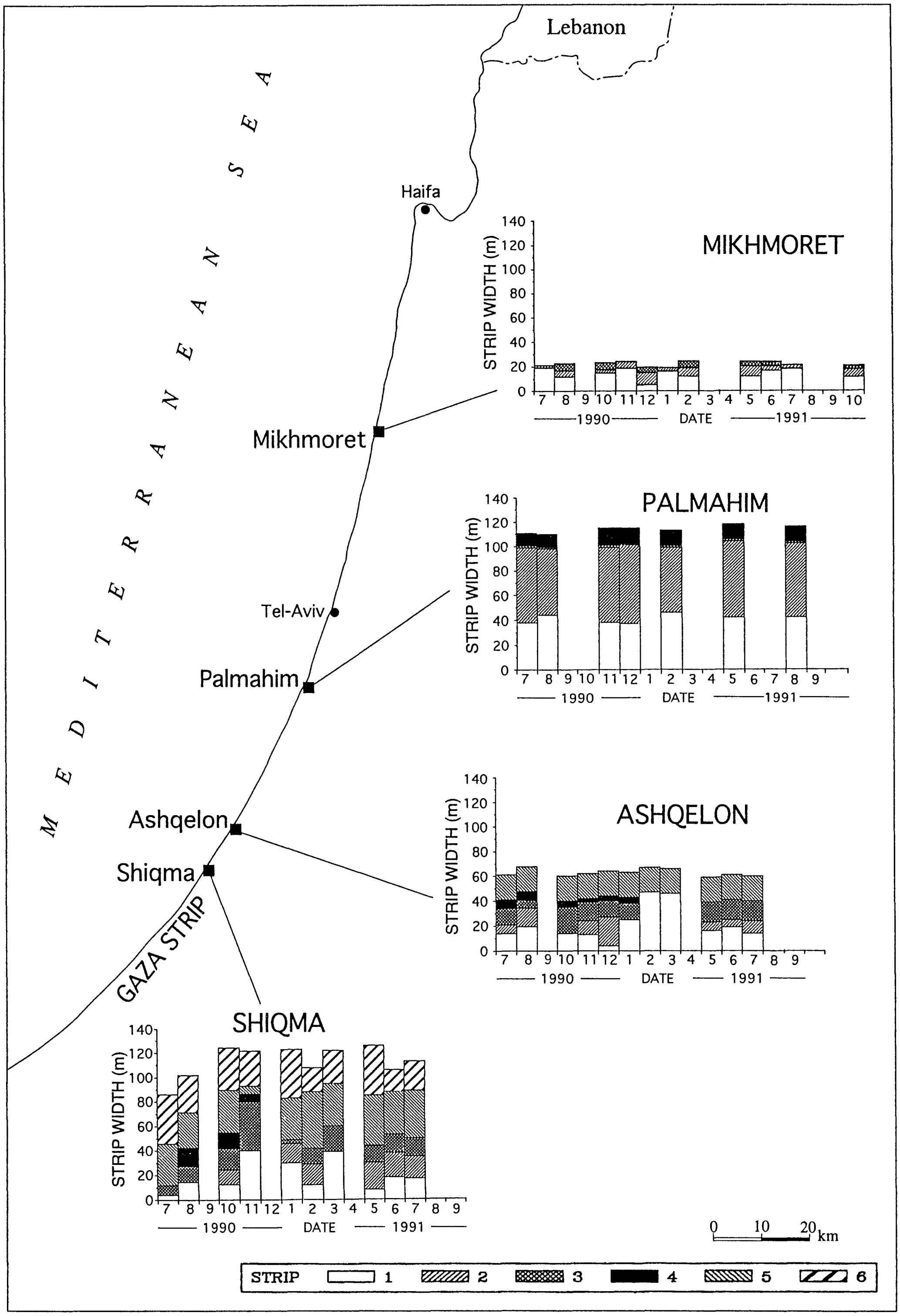

Figure 10. Mobility of the beach strips. Months are indicated by numbers. Note the stability of the strips of litter throughout the year on Palmahim beach. On the narrow Mikhmoret beach only three strips were recorded. Shiqma beach demostrates a dynamic migration of the strips.

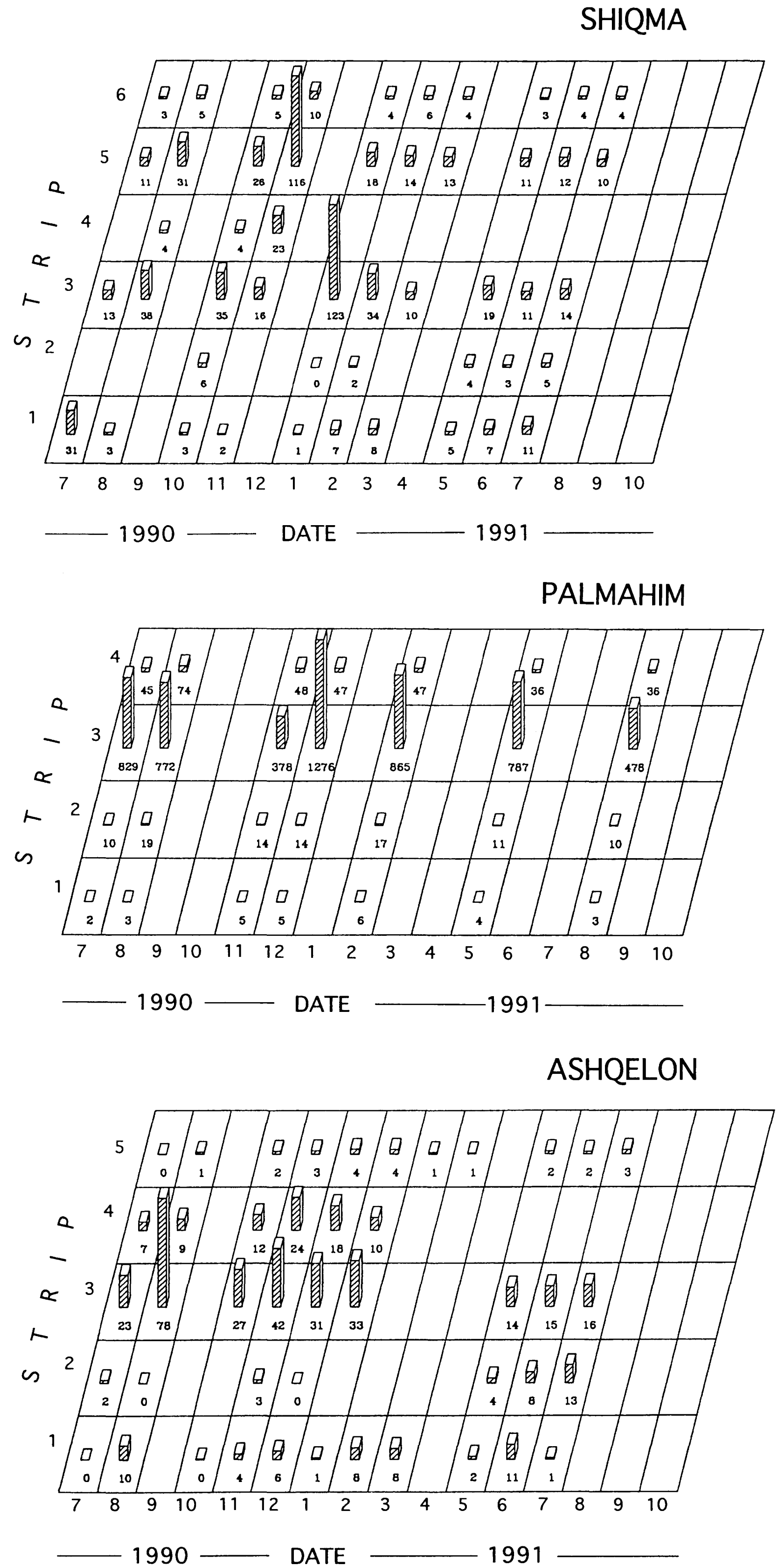

Figure 11. Density of the litter on the beach shown by strips numbered from the foreshore to the wind-dominated backshore. Months are indicated by numbers. Strips 3 and 5 on Shiqma beach reflect two levels of storms. Strip 6 is the far backshore and strip1 is the foreshore. Strip 3 on Palmahim beach reflects trapping of litter in a runnel. In Ashqelon beach the litter concentrated on the upper berm.

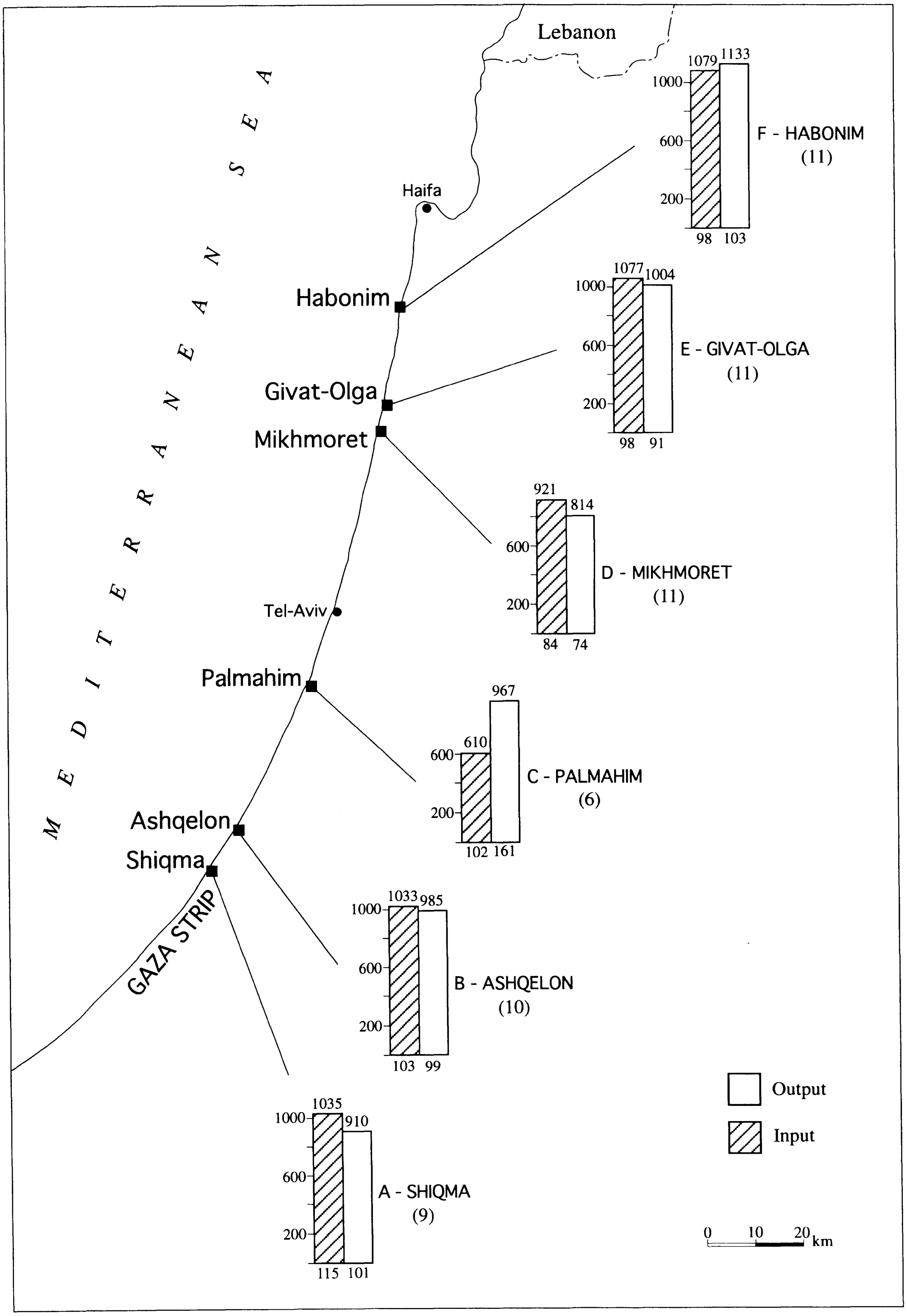

Figure 12. Summary of input and output of litter quantities during the study period. Number of sampling sorties is given below the name of each site. The overall number of input or output items during the study period is given above the bars. The mean number of items during the study period is given below the bars. Note similar quantities in most sites indicating a homogeneous coast with a quasi-balanced budget of litter.

es of litter per 1 m beach front. The very limited (<1%) area of litter coverage indicates that beaches need only a very small fraction of their area to be littered in order to appear environmentally spoiled.

Litter behavior along the Mediterranean beaches of Israel shows seasonal trends. Similar seasonal behaviour of litter, with the cleanest beaches during the stormiest season, was reported by GARRITY and LEVINGS (1993). Litter accumulates during the summer, reaching maximum in autumn. Low magnitude of litter is abundant during winter with the minimum towards the spring. These findings fit GOLIK and GERTNER's conclusion (1992) of least polluted winter beaches in December to February and most polluted in March to May. The negative litter budget at the start of winter supposedly reflects the "sweeping" of the beaches by the first winter storms of November to January (Figure 2). At the start of the recreation season the beaches are relatively clean. It seems that the seasonal behaviour is the result of two "converging" processes , *i.e.,* the seasonal wave climate and the littering by summer beachgoers.

The magnitude of littering on beaches not visited by bathers (Shiqma, Palmahim) is quite constant the year through. Ashqelon being more intensively visited, shows a clear seasonal budget. The Israeli Mediterranean coast is quite homogeneous in its high mobility of litter, shown by the similar litter input and output and by the almost balanced budget on the studied sites (Figure 12), regardless of morphology.

Based on the weekly surveys during August 1990 (Figure 5), the quantity of litter entering and leaving the beach each week, is a few scores to a few hundreds of pieces of litter. The accumulative entering and leaving litter on each of the study sites, based on 6–11 sampling operations (Figure 12), when compared to the magnitude of the litter settled on the beaches (Figure 4), suggests that the turnover time, i.e., the time needed to replace the total litter on each beach, is only a few months long and less than half a year. Palmahim and Shiqma would need a longer period.

DISCUSSION

In former studies (GOLIK and GERTNER, 1992) the density of the bathers and the winter storms were suggested as the most dominant factors controlling litter quantity on the beach. Beach geomorphology was not given the attention it deserves. The relationship of swash energy to beach width is a dominant factor which controls litter stability on beaches. It determines trends of accumulation versus backwashing and self-cleaning (CUNDELL, 1974; SCOTT 1975; DIXON and COOKE, 1977; DIXON and DIXON, 1981; WILLOUGHBY, 1986; CAHOON, 1990). The widest beaches in this study—Shiqma and Palmahim—are the most littered (Figure 4). The intensive littering of the Shiqma beach, despite the fact that it is not a public bathing site, highlights the importance of beach width. TSOUK *et al.* (1985) reached the same conclusion in their study on oil-polluted Israeli beaches. Their widest beach ranked lowest in self-cleaning. In spite of its width, the Shiqma beach lags behind the most littered Palmahim beach, which is almost closed to the public. This comparison highlights beach morphology as controlling the magnitude of litter. Palmahim is a very wide beach with a well-developed, stable ridge and runnel morphology which prevents seasonal migration of the litter strips, migration which is typical of the flat beaches studied. Being out of reach for visitors, Palmahim poses an excellent control site for evaluating the effect of human littering versus littering by the sea. Here, no maximum summer littering occurs. Palmahim does not obey any seasonal behaviour.

The limited littering of Ashqelon (Figure 4), although much busier than Shiqma and Palmahim, seems to reflect its relative narrowness. Similar beaches are abundant along the central coastal plain of Israel. Similarily, TSOUK *et al.* (1985) found Mikhmoret to have the greatest self-cleaning capacity in terms of removal of subsurface tar pollution from the entire width of the beach.

The specific beach morphology is also a controlling factor: a well-developed ridge and runnel morphology which reflects a depositional trend, supports drainage towards the runnel, thus protecting against backwashing and making the backshore an efficient trap for litter.

High beach porosity is a most dominant physical factor. It increases the subsurface beach drainage and diminishes the backwash, thus preventing self-cleaning and encouraging litter accumulation. Givat-Olga, inspite of its narrowness, represents mainly the trapping effect of a gravelly, highly porous beach, aided by some sheltering effect of fallen eolianite blocks.

We may conclude that on the studied Mediterranean Israeli beaches, coastal pollution seems to reflect beach geomorphology, with beach width, ridge and runnel morphology and beach porosity as dominating factors.

Most Israeli beaches are narrow, of the Ashqelon–Mikhmoret type. Narrowness contributes significantly towards a high litter flux, preventing the backshore and the coastal dunes from becoming sinks for litter. In other words, reflectivity decreases longevity of pollutants on beaches (ANITA, 1993). High mobility of litter means poor persistence and a good self-cleaning capacity. Our data highlights the mobile character of the litter and suggests that the Israeli beaches are essentially transfer stations for the migrating litter. However, even the narrowest sandy beach studied—Mikhmoret—is not narrow enough to stay clean continuously the year through. The litter migrates along the studied beaches and finally seems to bypass them. This longitudinal migration has not yet been studied, neither has the final sink been determined.

Continuous beach cleanup countermeasures seem the only answer for keeping the Israeli Mediterranean coast cleaner than nature can. However, these will only form temporary "cleaner periods" in the everlasting stream of litter along the coast.

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