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The environmental impact of marina development on adjacent beaches: a case study of the Herzliya marina, Israel

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Abstract

The objectives of this study were to identify coastal changes to the north and south of the Herzliya (Israel) marina using remote sensing techniques, and to compare them to the changes forecast by a physical model built by the Coastal and Marine Engineering Research Institute, at the Technion, Israel Institute of Technology, Haifa, Israel (CAMERI). The initial physical model output predicted coastal erosion north of the marina. The proposed solution to this problem was the building of detached breakwaters, complying with the planning demands and confined to the area studied. By adding such breakwaters, the model predicted soil accumulation and under-predicted the degree of erosion. It is clear from ground evidence that this solution only 'pushed' the area of erosion northward. The model also did not predict coastal erosion already occurring 750 m north of the marina and ignored any changes in the area south of the marina. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Coastal changes; Coastal erosion; Israel; Marina development; Remote sensing

Introduction

Development in coastal areas, primarily marinas, breakwaters, jetties and groynes, is the focus of considerable research activity by both natural scientists and planners. The Integrated Coastal Zone Management (ICZM) concept (Bird, 1996; Clark, 1996; Post & Lundin, 1996) has emerged since the 1970s due to (a) the irreversibility of

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the effects of development on coastal zones and the synergy of the impacts; and (b) the fact that about 180 nations are located along coasts.

Compared to many coastlines, that of Israel has been well studied. The primary sediment source is the River Nile. Nile sands have been transported from the outlets of the river to the Israeli coast by consistent west-to-east and southwest-to-northeast longshore currents generated by westerly approaching waves (Emery & Neev, 1960; Goldsmith & Golik, 1980; Nir, 1982, 1989). In recent decades the coast has been plagued by a serious shortage of sand and by erosion. The sand shortage results from both sand mining (illegal since 1964) and the building of coastal structures that are acting as sediment traps and therefore causing sand shortages on adjacent beaches.

The Herzliya marina is the first of 13 proposed marinas to be planned and implemented under the Israeli National Development Plan (NDP) 13A, (Brachia, 1987). It was built between August 1990 and the autumn of 1992 (Fig. 1) and the lessons learned from studying the sedimentological and morphological changes that have taken place along the coast since its construction are critical in order to predict more accurately the order of magnitude of impacts of future marinas. Detailed plans and expected environmental impact were meticulously studied prior to marina construction and were approved by the planning authorities, which saw it as a precedent for further marina development in Israel. As a prerequisite to granting approval, the authorizing bodies demanded that a scaled physical research model be run in a wave pool (Finkelstein, 1987). This demand for a physical model was based on an understanding that the marina would bring about changes in the coastline, through sediment transport and possible cliff retreat. The significance of this current study is that it not only compares coastal processes before and after marina construction, but it also compares the model's predictive capabilities with the actual impacts. This has ramifications for the degree of certainty that decision-makers should attribute to models of this sort in making critical planning decisions.

The pre-construction study modelled an area extending 3.5 km along the beach, 1.5 km either side of the proposed marina. The model was built by CAMERI (Coastal and Marine Engineering Research Institute, at the Technion, Israel Institute of Technology, Haifa, Israel) at a reduced scale following the scale relationships for model studies. Running the model indicated that erosion was to be expected to the north of the planned marina. As a counter-measure to this, three alternative forms of detached breakwaters were suggested to ensure compliance with the demand for shoreline preservation and even enrichment (Finkelstein, 1987). After examining all three alternatives, it was suggested that the third option be adopted for optimal shoreline protection north of the marina. This predicted that the coastline would have a crescentic shape throughout the protected area, that the area of the coast would increase by about 10 000 m^2, and that the effect on the neighbouring beach would be minimal (see Fig. 2).

The Mediterranean coasts of Israel and northern Sinai and their sedimentological aspects have been studied in some detail. Nir (1982, 1989) examined the influence of offshore artificial structures on the Israeli coast, while Koplik (1991) studied the morphodynamics of the coast, reporting the grain size distribution and the seasonal

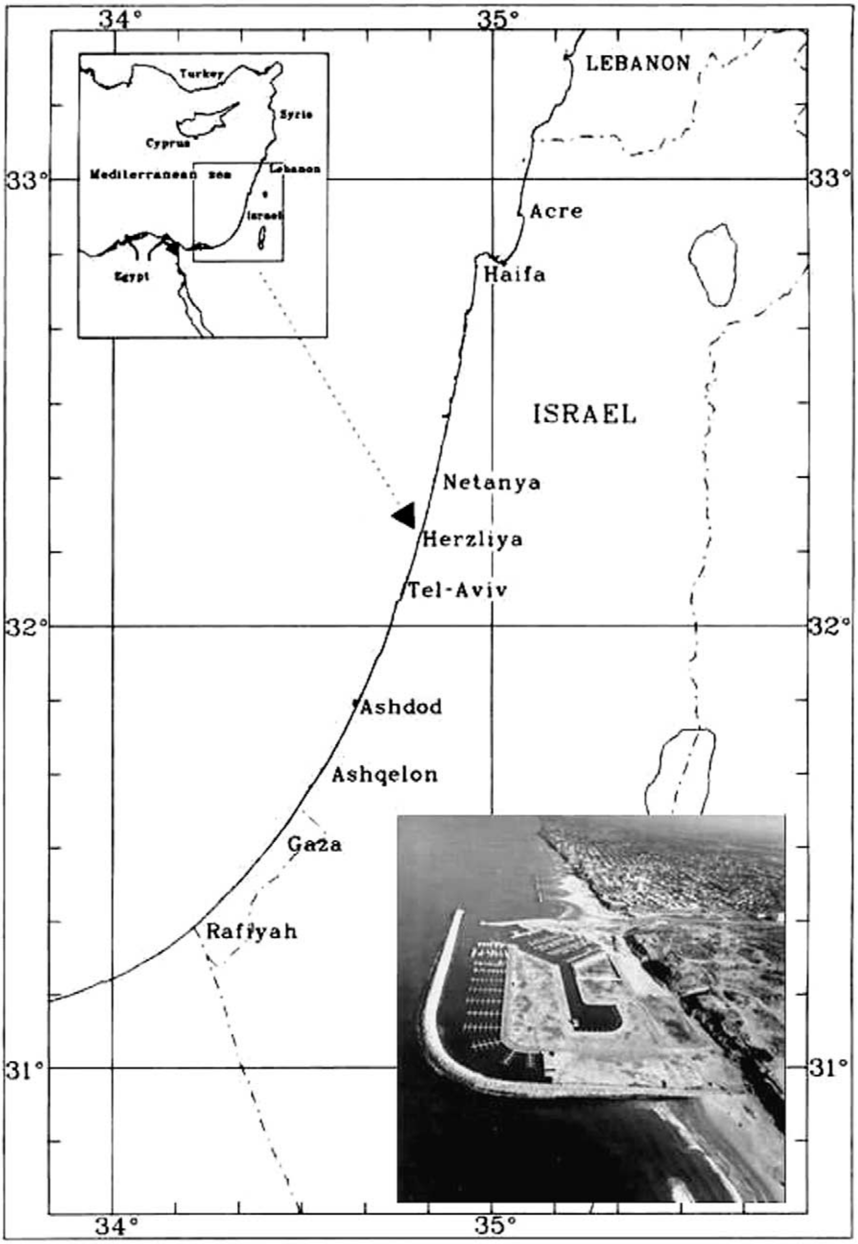

Fig. 1. The Herzliya region and the study area.

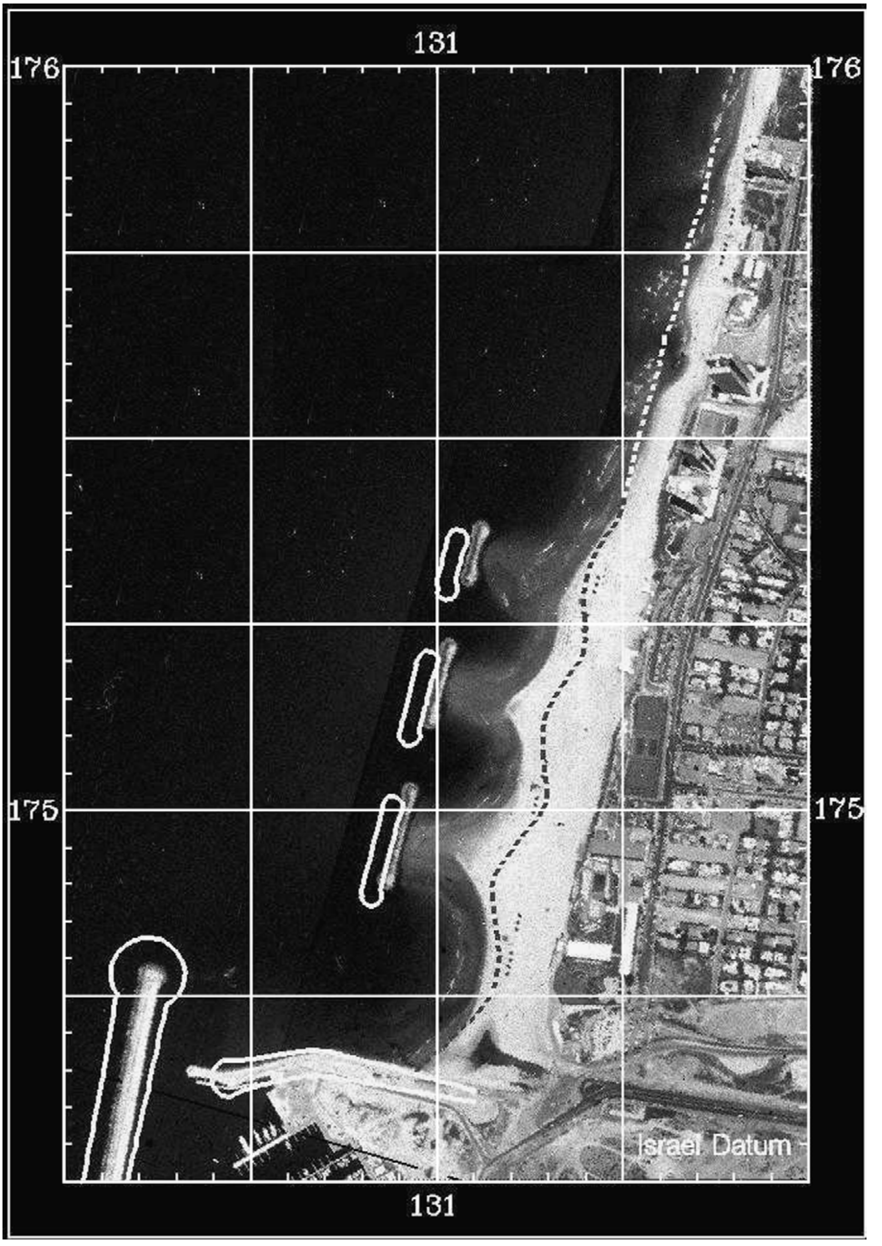

Fig. 2. The predicted shoreline for the option C sedimentological balance (dotted line) superimposed on background aerial photograph No. ML/538 (8 June 1996) showing the observed waterline.

coastal changes in Herzliya. Coastal changes in Herzliya were also studied by Libler (1994), who reported erosion north of the marina, in a study carried out during and after a unique winter season during which significant wave height rose to 7.2 m in Ashdod, 30 km south of Herzliya (6 February 1992). According to Nairn and Baird's (1996) report of coastline changes in the area north of the marina, the beach was 40–50 m wide in 1989, while in the winter of 1995 the width was only 15–40 m. Rosen (1998) studied the predicted potential impact of artificial islands on the sedimentological processes along a 50-km long segment that included the Herzliya area.

The objectives of the present study were twofold:

1. to monitor coastal changes to the north and south of the Herzliya marina by using remote sensing techniques, and
2. to compare observed coastal changes with changes forecast by the physical model built by CAMERI (Finkelstein, 1987) in order to assess this type of modelling as a planning tool for future proposed developments of like kind.

Methodology

Comparative mapping of the coastline from aerial photographs of the area utilized digital techniques. The mapping process included: scanning the photographs, calculating scanning resolution, determining control points, warping the photographs and determining rules for defining the actual coastline in the various photographs. In the final stage, digital vector mapping of the coastline in the various photographs was prepared. The characteristics of the various photographs used in this study are given in Table 1 (see also Zviely, 2000). To achieve the right comparison between the

Table 1
Aerial photograph characteristics

	Prior to marina construction				After marina construction				
Date	14.08.65	13.04.79	13.07.84	26.04.90	27.03.91	04.09.92	05.11.93	08.06.96	09.11.97
Time	12:55	14:14	08:57	10:43	14:45	15:29	13:10	11:24	14:47
Flight no.	MM100	MM600	AM005	AM195	AM866	AM319	AM383	ML538	OFEK
Photo id. no.	4343	8416	10 4164	8048	5045	1022	9139	5539	7325
Height (m)	2800	2820	–	6100	1960	2050	2860	6200	
Focal length (mm)	115.42	152.04	153.05	153.05	153.05	153.05	153.05	153.26	153.05
Scale	1:16 300	1:11 800	1:12 600	1:41 200	1:12 400	1:14 000	1:18 900	1:40 450	
Photo resolution (cm)	24.45	17.70	18.90	61.80	18.60	21.00	28.35	60.67	

various photographs, the wave set-up at the time of each photograph was calculated, based on wave data from Hadera (30 km north of Herzliya) and Ashdod (30 km south of Herzliya) (Zviely, 2000). In order to compare the results of this mapping process with the forecast results, the maps attached to the laboratory results were scanned and digitally captured in a vector file. These maps were also warped using control points. The marina structure was also digitized, as well as the breakwaters and the 0-level contour (the coastline).

Results

Morphological changes

The waterline of two segments in the study area, in the various photographs, is presented in Fig. 3. Measurements of the coastal area (between the waterline at each photograph and an arbitrary straight line along the base of the cliff in the study area) are presented in Table 2.

The study findings show that the sediment balance of the whole Herzliya beach area, in the period 1965–79, tended to be negative. This observation is based on the advance of the waterline towards the cliff (landward) by an average of 6–12 m and a decrease in the dry shore area by approximately 40% in 1979 relative to 1965. During the years 1979–90, the overall sediment balance for the area tended to be positive, as evidenced by recession of the waterline from the cliff by an average of 15–25 m and a significant enlargement of the dry shore area by 150–200% in 1990 relative to 1979.

Between the years 1990 (the beginning of the marina construction) and 1997, the changes in the position of the waterline were not uniform along the study area, being dependent upon the relative position of the coastal segment investigated with regard to the marina and the detached breakwaters to its north.

Based on these findings, we can divide the Herzliya coast within the study area into two categories, distinguished by the changes in position of the waterline between 1990 and 1997. The first includes areas with coastal erosion, including the coast of Herzliya at a distance of 1000–2500 m to the north of the lee breakwater of the marina, as well as the segment at a distance of 500–1000 m to the south of the main breakwater. An advance of the waterline towards the cliff of 12–15 m is accompanied by a substantial decrease (by 35–45%) in the dry sandy shore area between 1997 and 1990. Hence, the sediment balance on these shores had a negative trend during this period.

The second category comprises areas with coastal accumulation, including the shore behind the detached breakwaters and that just south of the marina. Along the shore, behind the detached breakwaters to the north of the lee breakwater, the recession of the waterline from the cliff base averaged 53 m, resulting in an increase of 131% in the dry shore area in 1997 relative to 1990. The sediment balance along this segment showed a positive trend between 1990 and 1997. Along the shore immediately south of the marina, there was less recession of the waterline from the

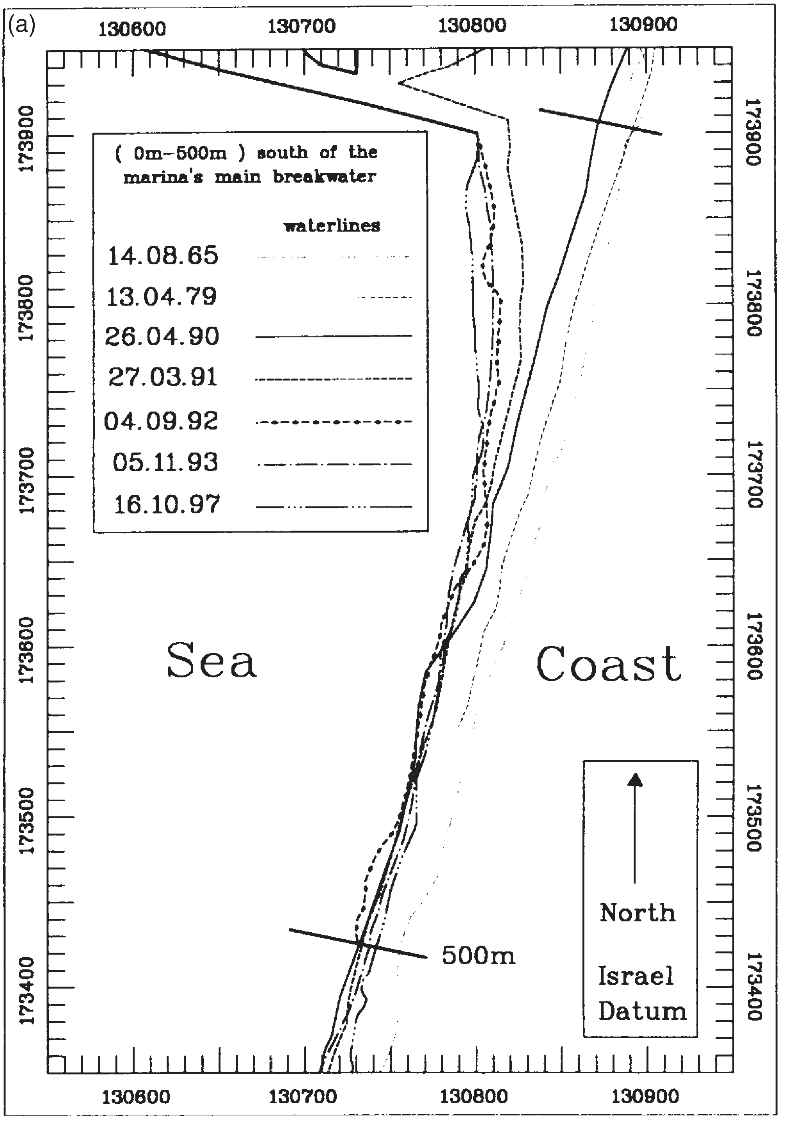

Fig. 3. (a) The waterline as shown on aerial photographs (1965–97) for the first 500 m of coast south of the marina's main breakwater.

cliff base (about 15 m), accompanied by a 26% increase in the dry sandy shore area in 1997, relative to 1990. The impact of constructions similar to those of the Herzliya marina, in areas with similar morphological parameters, have extended to about 2.5 km to the north and 1.5 km to the south on the adjacent shores (Rosen, 1992; Degani,

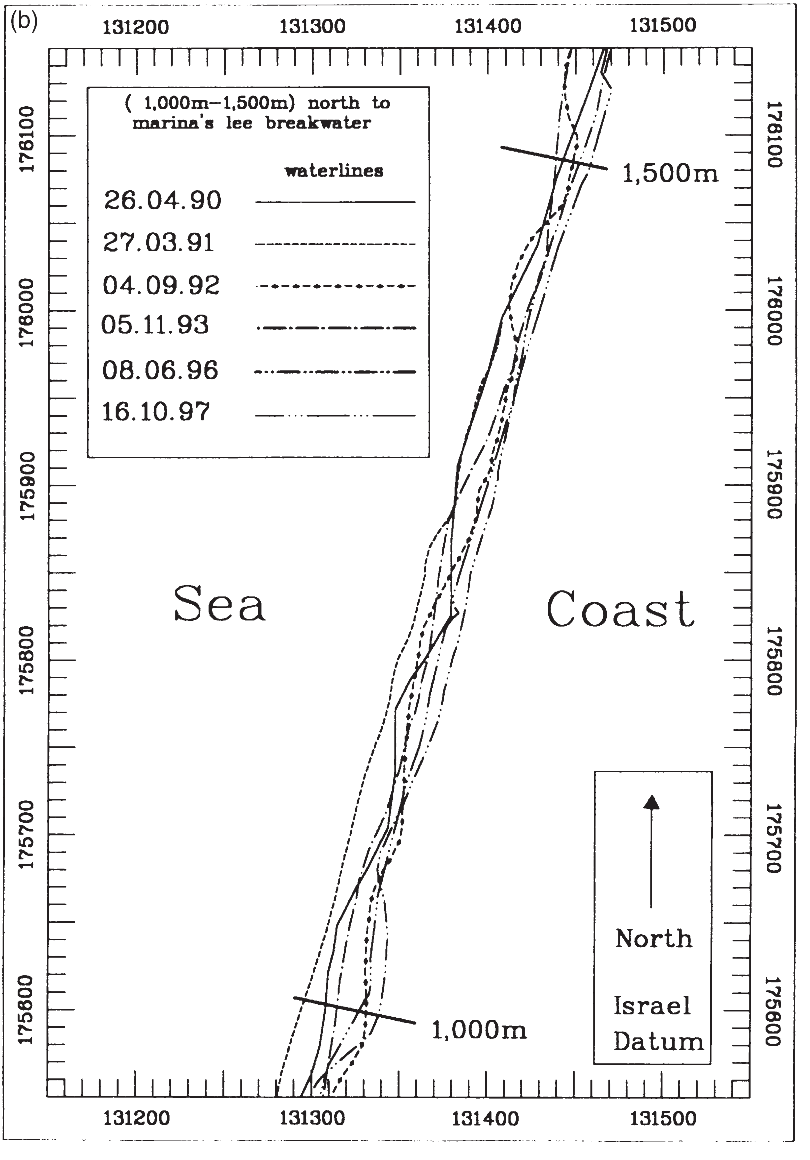

Fig. 3. (b) The waterline as shown on aerial photographs (1990–97) for the coastal segment 1000–1500 m north of the marina's lee breakwater.

1994; Haimi, 1998). In the case of a larger structure, such as the Ashdod harbour, impacts have extended as far as 4–5 km (Golik, Rosen, Golan, & Shoshany, 1996).

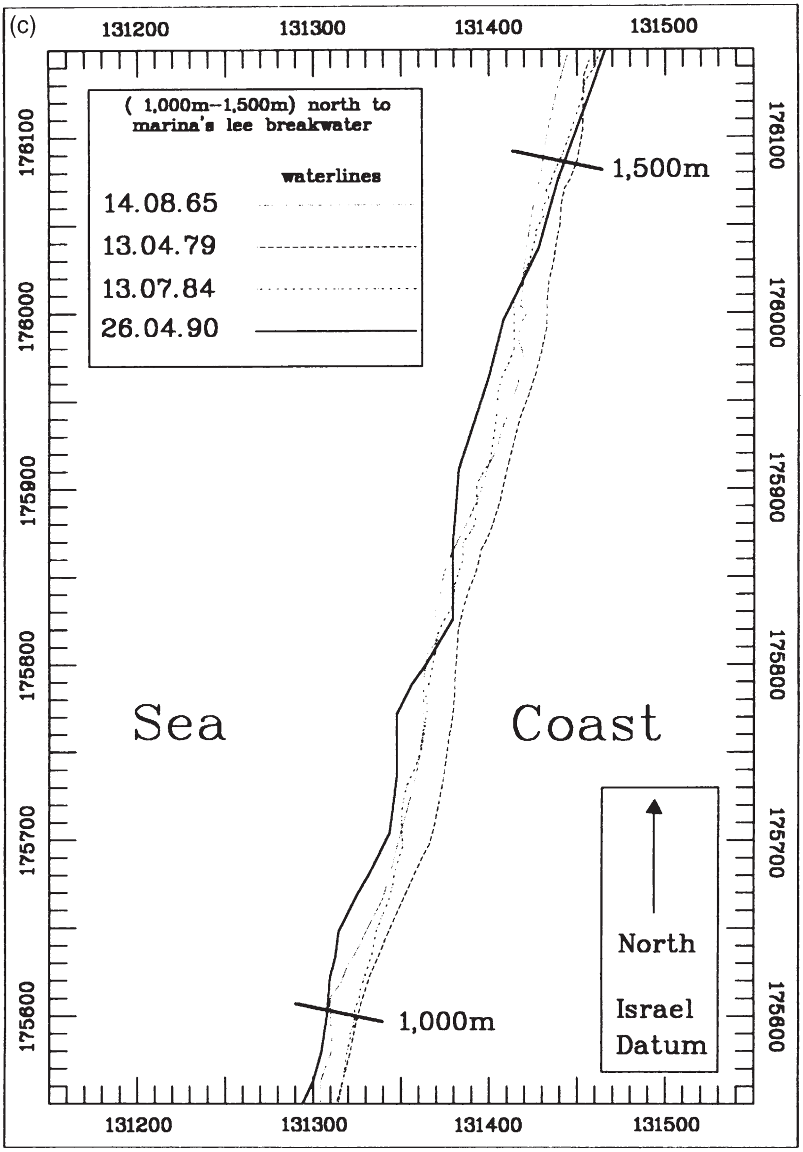

Fig. 3. (c) The waterline as shown on aerial photographs (1965–90) for the coastal segment 1000–1500 m north of the marina's lee breakwater.

Comparison of predicted and actual impacts

The structure of the marina, the detached breakwaters and the predicted coastline as they were scanned from the final report maps were superimposed on an orthophoto

Table 2
Changes in beach area along the Herzliya coast (m^2)

Date	500–1000 m south of marina	0–500 m south of marina	Along the marina	0–1000 m north of marina	1000–1500 m north of marina	1500–2000 m north of marina	2000–2500 m north of marina
14.08.65	**	7 700	22 840	25 350	16 210	**	**
13.04.79	**	**	17 690	25 780	9 200	**	**
13.07.84	**	**	**	26 870	15 270	14 460	12 790
26.04.90	22 770	21 480	36 690	40 980	19 200	13 350	14 570
27.03.91	**	24 040	51 000	55 440	23 110	**	**
04.09.92	**	27 590	***	47 250	15 535	**	**
05.11.93	24 770	26 940	***	86 520	17 425	**	**
08.06.96	18 090	25 330	***	89 280	11 310	9 200	8 170
09.11.97*	14 020	27 160	***	94 840	12 410	7 350	**

* Data from Rosen (1998), based on photogrametric mapping by DataMap; ** No data; *** No data due to the marina construction.

of the study area dating from 1990, just before the construction of the marina (see Fig. 2).[1]

In the area behind the detached breakwaters, accumulation was predicted, but actual accumulation was far greater than that shown by the model. The actual coastline is some 30–40 m west of the predicted coastline, and the additional coastal area in this section is about 30 000 m^2. The predicted shape of the coastline was a crescent, while the observed line shows the development of a tombolo. North of the detached breakwaters minor changes were predicted and the observed coastline is approximately 25 m east of the predicted line.

The model, although applied to the areas north and south of the marina, did not predict any changes in the coast to the south. However, the observed coastline south of the marina reveals a zone of accumulation within 300 m of the marina, and at a distance of 500–1000 m south of the main breakwater the coastline is some 12–15 m east of the coastline in 1990.

Conclusions

The initial physical model output predicted erosion of the coastline north of the marina. The solution to this problem was the building of detached breakwaters, which complied with the planning demands and were confined to the area studied. It is clear, however, that this solution only served to 'push' the area of erosion northward.

[1] There is a displacement of the detached breakwaters. In the model they were planned to be some 25 m west of the location where they were actually built. It may be argued that any further comparison is invalid, as such displacement is the reason for an increase accumulation of sand in the shore behind the detached breakwaters.

In several respects, the model failed to predict the effect of the marina with sufficient accuracy.

- Although, after adding the breakwaters, it did predict sand accumulation, this was much less extensive than the accumulation that actually occurred.
- It predicted a crescent-shaped coastline in all the protected areas, yet the actual coastline has developed a tombolo shape.
- It did not predict coastal erosion at a distance of 750 m from the marina.
- It ignored any changes in the area south of the marina.

The gap between the predicted and the observed coastal changes raises the question of whether the demand for a physical model is appropriate prior to construction of a marina of this size. The case study presented here shows that despite being constructed by a leading research institute, the model failed to predict the changes accurately.

It is important to remember that neither the models themselves nor their ultimate use in the planning process are neutral or objective. A model portrays in mathematical terms a set of relationships between variables. Some real-world relationships are extremely difficult to represent in mathematical terms. The choice of which variables and which relationships to include is a subjective one, based on researchers' knowledge, intuition and views of these relationships. Time seems to indicate one thing clearly – we do not know enough about cumulative impacts on coastal environments. Thus, the role of models in coastal zone management should be regarded as only one of many inputs – and one to be assessed with a great deal of uncertainty – in an arsenal of tools guiding decision-makers in the development of frameworks for the immediate and future allocations of this increasingly scarce resource.

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