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Seascape architecture – incorporating ecological considerations in design of coastal and marine infrastructure

Shimrit Perkol-Finkel[a,*], Tomer Hadary[a], Andrew Rella[b], Raviv Shirazi[a], Ido Sella[a]

[a] ECOncrete Tech Ltd.,4 Yehoshu'a Bin Nun St., Tel-Aviv, 6264304, Israel
[b] ECOncrete Inc., 311 West 85th Street, Suite 3, Manhattan, NY, 10024, United States

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ABSTRACT

With nearly 60% of the human population concentrated around the coastlines, alongside growing threats from sea level rise and increased storminess, accelerated coastal development is inevitable. As most marine flora and fauna reside in coastal areas, anthropogenic changes to coastlines are a key reason for loss of coastal habitats, and associated ecosystem services. While coastal infrastructure such as seawalls or breakwaters add significant amounts of hard substrate for marine organisms, they do not support similar species assemblages to those of natural habitats. This is mainly due to design features related to steep slopes, low structural complexity, and high homogeneity, all of which are rarely found in natural habitats. This study provides an example for seascape architecture of coastal structures using ecologically sensitive designs and concrete technologies that enhance the structures' biological and ecological value while contributing to structural integrity. Four 1.5 mx0.8 m seawall panels made of bio-enhancing concrete with high structural complexity were deployed in an active marina (Herzliya, Israel). The panels, spanned from the Mean High Higher Water (MHHW) down to the sublittoral zone, were surveyed 2, 7, 12, 18 and 22 months post deployment using 0.3 × 0.3 m quadrats in both intertidal and sublittoral zones of each panel. Bio-enhanced panels were compared to fixed control quadrats comprised of scraped sections of the original concrete marina seawall.

Results demonstrated the effectiveness of applying ecological considerations for biological and ecological enhancement of active infrastructure. All community parameters examined (live cover, richness, biodiversity) were significantly higher on bio-enhanced panels compared to controls. Moreover, mobile invertebrates and resident fish species were clearly enhanced through design aspects (holes and crevices) of the bio-enhanced panels. The study provides an example of an emerging approach of assimilating ecological considerations into the design and construction of working waterfronts and active coastal infrastructure, thus reducing their ecological footprint without compromising their operational performance.

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1. Introduction

Nearly 60% of the human population is concentrated in coastal areas, less than 100 km from the shoreline (Vitousek et al., 1997), resulting in extensive shoreline alteration including shoreline armoring. The latter, often results in the severe alteration or even complete destruction of natural shorelines and is considered to be the main cause for the loss of shallow water habitats (Airoldi and Beck 2007; Bulleri and Chapman, 2010). Most marine flora and fauna reside in coastal areas and anthropogenic changes to coastlines are a key reason for loss of coastal habitats, and associated ecosystem services (Spalding et al., 2007). These affected ecosystems provide food, shelter and nursing grounds for a variety of invertebrates, algae and fish. Coastal infrastructure, such as ports, marinas, revetments and breakwaters frequently replace these rich natural habitats and intensify the pressure on these fragile ecosystems (Dugan et al., 2011). The traditional low surface complexity and non-natural composition of coastal infrastructure, does not provide suitable conditions for the development of diverse biological assemblages (Firth et al., 2016). As a result, such structures are often dominated by nuisance and invasive species (Mineur et al., 2012). Concrete for example, which is widely used in coastal and marine construction, provides a poor substrate for marine flora and fauna, usually supporting low biodiversity and a high proportion of invasive species due to its high pH levels, and as a result of leaching of various hostile compounds and associated chemical materials

* Corresponding author.
E-mail addresses: shimrit@econcretetech.com (S. Perkol-Finkel), tomerh@searc-consutling.com (T. Hadary), andrew@econcrete.u (A. Rella), raviv@econcretetech.com (R. Shirazi), ido@econcretetech.com (I. Sella).

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used for its construction (McManus et al., 2017; DEC, 2004; Lukens and Selberg, 2004).

As many countries are adopting strategies of "Blue Growth", aimed at supporting sustainable management of marine resources in the maritime sectors, incorporation of environmentally sensitive technologies to active ports and marinas requires further investigation.

A major engineered component in ports and marinas is seawalls, often constructed from precast or cast on site concrete panels. Seawalls are typically built from repetitive units, with a vertical and featureless design, which support marine life to a limited functional degree (Browne and Chapman, 2014; Loke and Todd, 2016). While design modifications to the surface patterns of seawall panels have been previously tested in the US (Toft et al., 2013), Australia (Browne and Chapman, 2014), and Europe (Martins et al., 2010; Firth et al., 2014) the effectiveness of a combined enhancement strategy addressing both the design and the substrate composition of seawall panels has yet to be assessed. In response to this need, ECOncrete® Tech LTD has developed a series of concrete mixes and science-based designs which provide suitable biological and environmental conditions for the development of rich and diverse floral and faunal communities, while providing structural function and complying with all standards for marine construction. ECOncrete®'s technology was validated through a 2-year-long evaluation study conducted simultaneously in temperate and tropical environments (Perkol-Finkel and Sella, 2014). This study examined the isolated effect of concrete composition and of surface texture, indicating that the synergistic effect of bio-enhancing concrete compositions and roughed surface texture can dramatically increase the live cover, species richness, abundance, and biodiversity of benthic assemblages developing on concrete elements in the marine environment.

The study described here examines the impact of surface complexity and concrete composition on the biological performance of marina seawalls. The performance of bio-enhanced seawall panels, designed with increased surface complexity and proprietary concrete composition, were compared to standard Portland cement based seawalls. The experimental array was deployed in Marina Herzliya (Herzliya, Israel, East Mediterranean Sea, Fig. 1) on an existing concrete seawall constructed in 1995. Marina Herzliya, one of the largest and most modern marinas in the Eastern Mediterranean Sea, is located in the most densely populated coastal region in Israel, with over 3.6 million people. The active marina was chosen as a test site due to its relative proximity to submerged rocky reefs (only 300 m from the marina entrance), which provide diverse and unique habitats, therefore increasing the potential for biological recruitment. Moreover, as the site is a controlled area with restricted access, water quality or any disturbance events (e.g. oil spills) are well documented.

The study comprised a 22-month monitoring scheme comparing the community structure development on an existing concrete marina seawall, to that of bio-enhanced seawall panels. It was hypothesized that the bio-enhanced panels would develop a different community from that of the existing marina seawall, and that differences will vary with respect to depth (intertidal vs. sublittoral). We further hypothesize that bio-enhanced panels would increase the overall species richness, live cover, and the diversity of local flora and fauna, and will have a lower dominance of invasive species.

2. Material and methods

2.1. Preparation of bio-enhanced concrete panels

The bio-enhanced seawall panels were cast in September 2014, from a proprietary marine construction grade concrete mix (ECOncrete®) that has shown high recruitment capabilities in both laboratory experiments and field trials in several marine environments around the world (Perkol-Finkel and Sella 2014, 2015; Sella and Perkol-Finkel 2015). The seawall panels, (150 × 90 × 13 cm, weighing 420 kg) were cast in forms with liners designed to create a complex surface with diverse biological niches, including presence of holes (3 cm diameter, 12 cm deep) designated to provide shelter for invertebrates and fish.

2.2. Experimental array

In November 2014, four ECOncrete® seawall panels (ECO panels) were placed vertically, 1.5 m to 2 m apart, on an existing, south facing concrete seawall in Marina Herzliya, Israel (Fig. 1), using a flatbed truck with a crane (Fig. 2A-B). In order to achieve both intertidal and sublittoral sampling areas, and since the mean tidal amplitude in this region is ca. 30 cm (Einav et al., 1995), the ECO panels were placed with their top aligned with the Mean Higher High Water (MHHW) line, so that the upper 30 cm of each panel are exposed to intertidal conditions (Fig. 2C). Four intertidal and four sublittoral control plots were marked and scraped clean on the existing concrete marina seawall, at the same depths as the ECO panels (Fig. 2C). While a fully randomized experimental layout might have been preferable, this was not possible due to technical limitations, as panels were hung from pre-existing dock cleats. Nonetheless, there was a gap of at least 0.5 m between the edge of the ECO panels and the control plots, thus no interaction between ECO and control plots is expected, nor any shading effects or particular changes to flow regime as the site is relatively sheltered.

2.3. Monitoring

Before deployment, a baseline survey of the existing conditions on the marina seawall was conducted. Four 30 × 30 cm quadrats were set in the top intertidal, and four at the bottom sublittoral areas designated for the control plots. These were surveyed in-situ (Fig. 3) according to the protocol described below, and photographed using a Canon G15 Camera equipped with an underwater housing and fisheye lens to assist in the identification process. Once the baseline data were collected, the entire surface area surrounding the quadrats was scraped from organisms using a metal scraper to expose the original concrete seawall, thus qualifying as control plots. The in-situ visual monitoring of the ECO panels was conducted using the same quadrats. On each panel, one quadrat was randomly set in the intertidal area, and one in the sublittoral area, at both locations at least 15 cm from the edges of the panel. Thus, four intertidal and four sublittoral ECO quadrats were surveyed and photographed on each monitoring event, parallel to surveys of four control quadrats randomly set in the intertidal plots and four in the sublittoral plots. Note, that baseline data were not included in the statistical analyses as ECO and control plots were not colonized at time zero, thus no comparison could be conducted.

The experimental setup was monitored 2, 7, 12, 18 and 22 months post-deployment. During each monitoring event, divers started with a thorough visual inspection of the entire setup, noting mobile invertebrates and fish appearing on and in the vicinity of the panels and quadrats. Mobile organisms noted outside the quadrats were added to the overall species list (marked as a cross in Table 1), yet were not included in the statistical analyses. Once the broad survey was complete, divers conducted the detailed visual surveys of the quadrats.

Quadrat monitoring followed Perkol-Finkel et al. (2008), and included: overall live cover [%]; cover of encrusting species (sponges, tunicates, bryozoans, etc.) [%]; number of solitary organ-

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