TOWARDS AN ECOSYSTEM BASED PORT DESIGN PROCESS: LESSONS LEARNT FROM TEMA PORT, GHANA

by

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ABSTRACT

Connecting to the trend of harmonization of port developments with nature, this paper presents a framework for the explicit inclusion of ecosystem based alternatives in the early planning and design stages of seaport developments. The framework aims to shift the focus from offsetting environmental impacts afterwards to avoidance and reduction of environmental impacts as integral part of seaport planning and design. Our framework, labeled the *ecosystem based port design hierarchy*, helps to identify ecosystem based alternatives at 4 hierarchical levels of port planning and design: (1) consideration of alternatives to port developments to meet a perceived transport capacity problem (i.e. "no-port" alternatives), (2) port site selection, (3) port layout selection and (4) selection of port structures and materials. Application of the framework to the planning and design process of Tema port expansion in Ghana in hindsight shows that ecosystem based considerations barely played a role in alternative generation and evaluation. Therefore, opportunities for environmental impact avoidance and reduction may have been missed in the decision making process. It is recognized that decision making is a multi-disciplinary and multi-stakeholder process which is not based on environmental considerations only, but requires tradeoffs with functional, operational and socio-economic requirements. Nevertheless, we believe that explicit identification and inclusion of ecosystem based alternatives as part of this decision making process, as supported by our framework, is a requirement to arrive at port developments that are (better) harmonized with nature.

1 INTRODUCTION

Due to pressing global environmental concerns there is growing attention for harmonizing human developments, such as seaports, with ecosystems (Odum and Odum, 2003; PIANC, 2011; PIANC, 2014b; De Vriend et al., 2015; Nebot et al., 2017). Connecting to this trend, this paper provides a framework for the explicit inclusion of ecosystem based alternatives in the early planning and design stages of seaport developments. Recognizing that port planning and design starts from a scoping phase including a sound understanding of the physical, ecological and socio-economic context, this paper focuses primarily on the *design of options* step. Hence, we take a perceived transport capacity problem in a country or region as the starting point for our framework. The aim of our framework is to promote ecosystem based considerations in alternative generation in the early planning and design stages of port developments in order to increase the potential for avoidance and reduction of environmental impacts. At the same time we recognize that decision making is not only based on ecosystem and biodiversity considerations, but requires tradeoffs with functional, operational and socio-economic requirements. With this study we aim to make these tradeoffs explicit in the early port planning and design stages in order to enable transparent decision making.

We distinguish different hierarchical levels in port planning and design: (1) alternatives to a port development to resolve the identified (capacity) problem (i.e. "no-port" alternatives), (2) port site selection, (3) port layout selection and (4) selection of port structures and materials (see Figure 2). Ecosystem based alternative generation can take place at all the hierarchical levels and design choices made at higher levels narrow down options at lower levels. The identification of the hierarchical levels is based on three information sources: (1) the expertise in civil engineering

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(background of the chief author), (2) expertise from other fields (i.e. ecology, social science, economics) through open interviews with experts (see Annex A), and (3) literature review (see Table 1). This accords with Hevner et al.'s (2004) design science approach in which societally relevant and scientifically rigorous information sources co-determine the quality of the design process. The levels of port planning and design align with the steps suggested in port design handbooks (e.g. Thoresen, 2003; Ligteringen, 2012), with the exception that most of these handbooks take the choice for a port development as a starting point. According to Zheng (2015), the port location is also often taken as a starting point, implying that most of the port design exercises start from level 3 in the hierarchy. Moreover, planning and design considerations in port design handbooks are often primarily based on functional, operational and economic motivations rather than on ecosystems and biodiversity.

Taken together the different levels of port planning and design form a port design hierarchy. The focus of this paper is on the inclusion of ecosystem based considerations at each of these hierarchical levels with the aim of accounting for ecosystems and biodiversity at the highest possible level. Therefore, we label this approach as the *ecosystem based port design hierarchy*. This hierarchy aims to shift the focus from offsetting environmental impacts afterwards to avoidance and reduction of environmental impacts as an integral part of port planning and design (see Figure 2). What is feasible, at what level in the hierarchy, is situation specific.

This paper describes the *ecosystem based port design hierarchy* framework as well as the application of the framework to the case study of the Tema port expansion, located about 2 5km east of Ghana's capital Accra (see Figure 1). The paper is organized as follows: Section 2 describes the levels of the *ecosystem based port design hierarchy*. Section 3 provides the methodology for testing our framework based on the Tema case study. Consequently, the results of the case study application are described in Section 4. Finally, the conclusions are presented in Section 5.

Figure 1: Location of Tema port at the Ghanaian coastline

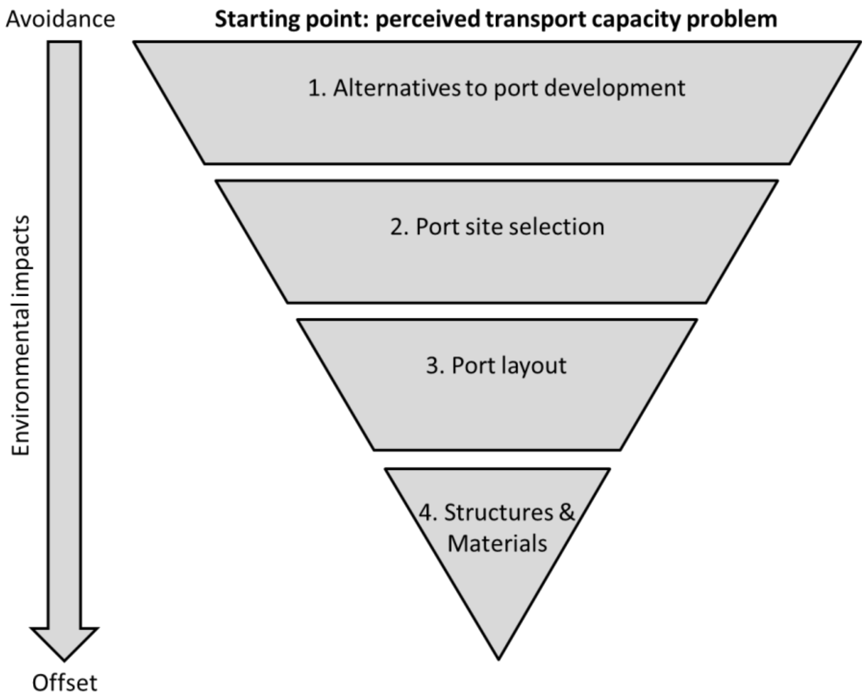

Figure 2: The *ecosystem based port design hierarchy* for avoiding/minimizing environmental impacts at the different hierarchical levels of port planning and design.

Level in port design hierarchy	Sources
1. Alternatives to port developments	Alemany 2005; Nebot et al, 2017; Robins, 2002; Xiao and Lam, 2017; Expert interviews & brainstorms
2. Port site selection	Alemany 2005; Diab et al., 2017 Nebot et al, 2017; PIANC, 2018; Schipper et al., 2015; SIGTTO, 1997 Tallis et al., 2015 Thoresen, 2003; Ligteringen, 2012; Zheng, 2015; Expert interviews & brainstorms
3. Port layout alternatives	Bakermans et al., 2014; Bruun, 1981, 1990, 1992; De Jong et al., 2012; Pachakis et al., 2017 Schipper et al., 2015 ; Expert interviews & brainstorms
4. Port structures and materials	Burt et al., 2009; De Vriend et al., 2015; Dekker et al., 2014; Mercader et al., 2017; Odum and Odum, 2003; Paalvast et al, 2012; Perkol-Finkel et al., 2017;

Table 1: Overview of information sources used for the development of the *ecosystem based port design hierarchy*

2 FRAMEWORK DESCRIPTION

As presented in Figure 2 the *ecosystem based port design hierarchy* framework consists of 4 hierarchical levels. The subsequent subsections describe these levels in more detail and discuss general examples of ecosystem based alternatives for each of the levels based on information obtained from the sources provided in Table 1.

2.1 Level 1: Alternatives to port development

The first level in the *ecosystem based port design hierarchy* considers alternatives to a port development in order to solve the perceived transport capacity problem. These “no-port” alternatives are not to be confused with the obligatory “do-nothing” alternative that has to be considered as part of a Social Environmental Impact Assessment (SEIA). As illustrated in the previous section a port development is one of the solutions to a perceived transport capacity problem, for example by expanding an existing (‘brownfield’) port or constructing a new (‘greenfield’) one. A downside of port developments is that they impact the environment in terms of air pollution, water pollution, waste disposal and, especially, dredging and civil works resulting in habitat loss/degradation (Peris-Mora et al., 2005; ESPO, 2012; Lam and Notteboom, 2014). From an ecosystem perspective it can therefore be beneficial to explore alternative solutions that have less environmental impacts to resolve the perceived transport capacity problem. Such alternatives can be sought for example in efficiency or utilization improvements of existing port infrastructure (PIANC, 2014a), redistribution or repurposing of existing port infrastructure (Xiao and Lam, 2017), increased cooperation between existing ports in the form of port networking (Robins, 2002; Nebot et al., 2017) or improvements of other transportation modes and their mutual connections (Nebot et al., 2017). Such alternatives may not avoid environmental impacts entirely, but at least minimize the need for (additional) dredging and civil works and, hence, avoid/minimize the environmental impacts associated with those activities.

2.2 Level 2: Port site selection

In many cases alternatives to a port development are limited or just not sufficient to resolve the perceived capacity problem entirely. At this stage it is assumed that a port development is inevitable. The next step in the *ecosystem based port design hierarchy* is then to select an appropriate site for the port development. From an ecosystem perspective extension and requalification of existing (‘brownfield’) port infrastructure is often preferred over construction of new ports (Alemany, 2005; Nebot et al., 2017). Since marine and terrestrial infrastructure are already in place for existing ports, the additional environmental impacts in these (already impacted) environments are likely to be less severe than the impacts of new ports in pristine environments. Also from an economic point of view extension or requalification of an existing port site may be beneficial compared to a new port site, due to the availability of existing infrastructure, hinterland connections, labor and supporting socio-economic infrastructure, resulting in lower overall costs for the development.

In some cases the development of a new (‘greenfield’) port is required, because the existing ports are located too far away from the location where additional transport capacity is needed or expansion of existing ports is impossible for physical or socio-economic reasons. In those situations port site selection can be crucial to avoid and minimize impacts on ecosystems and biodiversity (Tallis et al., 2015; Zheng, 2015; Schipper et al., 2015). From an ecosystem perspective the site selection should be such that the functioning and integrity of natural ecosystems is preserved. This means accounting for ecological requirements such as (1) habitat connectivity, (2) limited direct human interferences, (3) endogeneity, (4) species population viability, (5) opportunities for threatened species, (6) trophic web integrity, (7) opportunities for ecological succession, (8) zone integrity, (9) characteristic (in)organic cycles, (10) characteristic physical-chemical water quality and (11) system resilience (based on Slinger and Nava Guerrera, 2016). Accounting for these ecological requirements implies working with nature rather than working against or despite it (PIANC, 2011; PIANC, 2014b; De Vriend et al, 2015). Ideally, the site selection is such that the natural local conditions enable port functioning so that little human interferences are required. Such a location would be naturally sufficiently deep for navigation, allows for sufficient manoeuvring space and has sufficiently mild conditions (e.g. in terms of wind, waves and currents) to enable safe and efficient port operations (Thoresen et al., 2003; Ligteringen, 2012; PIANC, 2014a; Zheng, 2015; Diab et al., 2017). Additionally, such a site would be ecologically resilient, consisting of environments similar to those created by port infrastructure (e.g. vertical stony coastline) and neither biogeographically unique nor fulfilling a unique function for the regional ecosystem (e.g. in terms of migration routes or nursery function). Obviously, ecologically protected and sensitive areas should be excluded from the site selection process as much as possible.

2.3 Level 3: Port layout selection

After port site selection the next level in the *ecosystem based port design hierarchy* is port layout selection. The available design options for port layouts are highly dependent on the ambient natural conditions in terms of water depth, waves, wind and currents and, hence, constrained by the selected port development site. As discussed in Section 2.2, ideally site selection is such that natural conditions enable port functioning without human interferences in the natural system, but often human interferences in the form of dredging (e.g. deepening of port basin and access channels, land reclamations for quay infrastructure) and civil works (e.g. breakwaters, berths and quay walls) are required. From an ecosystem perspective these human interferences should be avoided or minimized as much as possible. Hence, port lay-outs with minimal needs for dredging and civil works are preferred from an ecosystem's point of view.

Traditionally seaport layouts consist of breakwater structures to provide shelter from ambient wave and current conditions (De Jong et al., 2012). However, in mild coastal environments, open or unsheltered port concepts have been suggested as an alternative to traditional port layouts (Bruun, 1981, 1990, 1992; De Jong et al., 2012; Bakermans et al., 2014). Such port layouts would decrease the amount of civil works required. This is not only interesting from an economic point of view, but also minimizes human interference in the ecosystem in terms habitat modification and segregation. The feasibility of open layouts depends very much on the hydro-geomorphological environment of the selected site as well as the typical vessel characteristics, port operations and available mooring and crane technology in the port (De Jong et al., 2012). Another alternative to traditional port layouts are offshore ports or terminals. Offshore ports or terminals are generally located at deeper water and, hence, require less dredging works to deepen port basins and access channels (Pachakis et al., 2017). This also holds for extensions of existing ports, where extensions in offshore direction are likely to be beneficial over alongshore port extensions in terms of required dredging works. Moreover, the coastal zone is often characterized by a higher habitat richness and biodiversity than the offshore zone due to larger heterogeneity (Gray, 1997; Ray, 1988). These richer habitats do not have to be displaced in case of an offshore extension. Although the feasibility of offshore layouts is highly situation specific, bigger ships and more sophisticated mooring systems offer more opportunities for offshore ports nowadays than in the past.

2.4 Level 4: Selection of port structures and materials

At the lowest level of the *ecosystem based port design hierarchy* the design freedom is constrained to choices with respect to the type of structures and materials to be used for the port infrastructure. Although possibilities to avoid environmental impacts at this level are generally limited, still ecosystem based design choices can be made to minimize environmental impacts, restore ecosystem functioning or enrich system complexity. As a starting point we assume at this stage that standard port infrastructure in the form of a sufficiently deep port basin with breakwaters and quay walls is required. Such infrastructure replaces natural habitats (Dugan et al., 2011). From a marine perspective such infrastructure adds a significant amount of hard substrate for marine organisms to attach to. However, the steep slopes, low structural complexity and high homogeneity of traditional port infrastructure do not provide suitable conditions for the development of diverse biological assemblages (Firth et al.,2016; Perkol-Finkel et al.,2017). Therefore, these structures are often dominated by nuisance and invasive species (Mineur et al., 2012). From a terrestrial perspective traditional port infrastructure not only homogenizes habitats, but it also excludes growth opportunities for plants and microorganisms which are essential for terrestrial ecosystems.

Over the past years advances in the field of ecological engineering (Odum and Odum, 2003; PIANC, 2011; De Vriend et al., 2015) have resulted in new concepts for multifunctional design of marine infrastructure also accounting for the ecosystem. Still this approach is rarely applied in the development of ports (Mercader et al., 2017). Examples of ecological engineering concepts for ports found in literature include breakwaters with an artificial reef function to support habitat richness and biodiversity (Burt et al., 2009), ECOncrete® to enhance the biological and ecological value of quay walls while contributing to structural integrity (Perkol-Finkel et al., 2017), artificial habitat creation to enhance the nursery function of juvenile fish by increasing habitat complexity (Mercader et al., 2017), surface complexity enhancement using novel resurfacing materials (Dekker et al., 2014) and pole and pontoon hulas (i.e. hanging ropes) to increase the productivity and biodiversity in the hard-substrate environment (Paalvast et al., 2012). If modifications to native habitats and the ecological functions they support are unavoidable due to the construction of port infrastructure, these ecological engineering options may help to create alternative habitats to sustain existing or support new ecological functions (Mercader et al., 2017).

3 CASE STUDY METHOD

In line with the design science approach of Hevner et al. (2004) we test our prototype *ecosystem based port design hierarchy* framework (or artifact) on a practical case study in order to evaluate its utility. For this we use the case study of Tema port expansion in Ghana. The aim of the application of the *ecosystem based port design hierarchy* to this case is primarily to test and illustrate our framework. With the application of our framework we (1) evaluate the inclusion of ecosystem based considerations in the planning and design process of the Tema port expansion based on available public information and (2) identify potential opportunities for ecosystem based alternatives that could have been considered at the different hierarchical levels in hindsight. Information on the case study is obtained primarily from the following sources (1) a site visit to Tema port, (2) open interviews with local stakeholders in and around the port and (3) preliminary, feasibility and environmental impact studies of Tema port expansion (JICA and GPHA, 2002; Halcrow, 2010; SAL Consult Ltd, 2015).

The port of Tema is located in the Greater Accra Region about 25 km east of Ghana's capital Accra. Presently, about 80% of Ghana's sea borne international trade, which is almost 90% of Ghana's total trade, is handled through port of Tema (Halcrow, 2010; SAL Consult Ltd, 2015). The port is mainly operated by the Ghana Ports and Harbour Authority (GPHA), except for a modern container handling facility that is operated by Meridian Port Services Ltd (MPS), a joint venture of APM Terminals International, Bollore Group and GPHA (Halcrow, 2010). The cargo consists mainly of containers, but also includes bulk, RoRo and oil & gas. Over the past years port of Tema has seen a significant increase in total cargo traffic from about 7.5 million ton in 2003 to 13.5 million ton in 2016 (GPHA, 2017). Due to the rapidly growing economy of Ghana and the potential for growth in transit trade through Ghana to the landlocked countries in the sub-region, the cargo traffic through port of Tema is expected to further increase in the future (SAL Consult Ltd, 2015). Also transhipment is a growing core activity of the port (Halcrow, 2010). To facilitate this growth a joint venture of the Ghana Port and Harbour Authority (GPHA) and Meridian Port Services Ltd (MPS) is currently expanding the port with container handling facilities (see Figure 3).

Tema port is located at the Ghanaian coastline with a gently sloping coastal profile towards the sea (SAL Consult Ltd., 2015). The port area is underlain by a system of rocks (Halcrow, 2010). The hydrodynamics are affected by the Guinea current, tide, wind and waves. The tidal current is generally less than 0.1 m/s (JICA and GPHA, 2002; SAL Consult Ltd., 2015). The alongshore currents in the nearshore are mainly driven by wind and waves with an average of about 1 m/s (SAL Consult Ltd., 2015). The waves are predominantly swell waves from the south-southwest originating from the Atlantic ocean with typical significant wave heights between 1 and 2 m (SAL Consult Ltd., 2015), resulting in an eastward directed littoral drift. Whereas the SEIA shows significant predicted sediment transport rates leading to up-drift sedimentation and down-drift erosion as a result of the port expansion (SAL Consult Ltd, 2015), indicating significant sand availability, the feasibility study of Halcrow (2010) states that suitable fill material in the vicinity of the port is scarce based on available soil borings. The latter is confirmed by stakeholder interviews during a site visit to Tema in 2017 (see Annex A). Sand in the vicinity of the port seems to be scarce and fill material for the port extension needs to be dredged from far offshore. Three lagoons are present in the immediate vicinity of the port: the Ramsar designated Sakumo II lagoon about 1 km west of the port, the almost fully silted Chemu lagoon just east of the port and the Gao lagoon about 3km east of the port (Halcrow, 2010). The Chemu lagoon serves as the major effluent drain for the industries of Tema and is heavily polluted. The Gao lagoon is also silting up and getting polluted by emerging industries in its vicinity. The Sakumo II lagoon is largely closed off from the sea after the construction of the Accra-Tema coastal road in the 1950's. Only supra tidal culverts provide a small connection to the sea. The brackish-saline lagoon consist of open lagoon, floodplain, freshwater marsh and coastal savanna habitats. It is a tourist point for sea and migratory bird watching, provides a source of livelihood for fishermen and has spiritual value for the communities living alongside the lagoon.

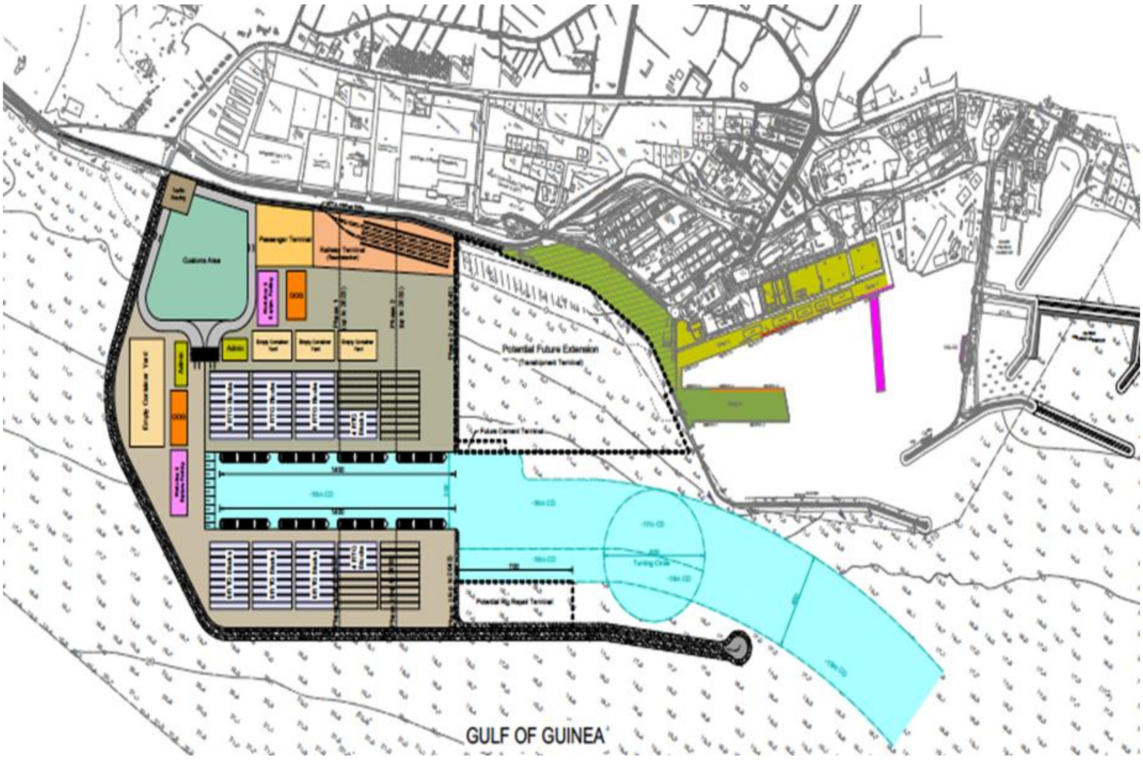

Figure 3: The planned expansion of Tema port (highlighted in full color) and the present port layout (in grayscale). Source: GPHA (2018).

4 APPLICATION OF THE ECOSYSTEM BASED PORT DESIGN HIERARCHY TO TEMA PORT EXPANSION

In this section we apply the *ecosystem based port design hierarchy* in hindsight to the case study of Tema port expansion. The aim of the application to the Tema case is both to test our framework in practice and to derive lessons learnt from the Tema case. The subsequent sections evaluate and discuss ecosystem based alternative generation at each of the levels of the port design hierarchy.

4.1 Level 1: Alternatives to port development

In the feasibility study for Tema port expansion (Halcrow, 2010) alternatives are explored in order to facilitate the expected growth in container throughput for which the capacity of the present facilities is not sufficient. International cooperation between the many West African countries with their own ports is not considered a realistic alternative, because of the lack of good coastal roads between adjacent ports as well as issues with customs and national pride (Halcrow, 2010). Therefore, the focus of the feasibility studies is on improvement of the existing port infrastructure in Ghana. In the feasibility study two noticeably different scenarios are considered: (1) a *gateway port* serving mainly Ghana and transit traffic with limited transhipment and (2) a *regional hub port* serving the above plus neighbouring countries via transhipment. The latter scenario involves much larger ships and a doubling of traffic volume in Tema compared to the former (Halcrow, 2010). In the *gateway port* scenario several alternatives are explored to upgrade the existing port infrastructure within the present breakwaters to expand the container handling facility. The limited dredging and construction needs of such a scenario would have been preferable from an ecosystem perspective. In the *regional hub port* scenario, ecosystem based alternatives to a port development in order to accommodate the larger vessels and traffic volumes for transhipment do not seem to have been feasible. The *regional hub port* scenario is eventually adopted for Tema port expansion.

4.2 Level 2: Port site selection

In terms of site selection only the existing ports of Tema and Takoradi were considered suitable in terms of size and facilities to accommodate for the increasing container throughput in Ghana. The choice of an existing port has several advantages over the construction of a new one in terms of the existing network, infrastructure and hinterland connections. The choice for Tema instead of Takoradi was based on the Tema's advantages in terms of more liner vessel calls, greater container berth draft and more modern container handling facilities, storage and management (Halcrow, 2010). The choice for the development of an existing port over the construction of a new one is also beneficial from an ecosystem perspective, because the additional impacts of a port expansion in an already impacted environment are likely to be less severe than the impacts resulting from a new port construction in a pristine environment (see also Section 2.2). Therefore, a more ecosystem based alternative in terms of site selection was probably not feasible in this case.

4.3 Level 3: Port layout selection

In the preliminary and feasibility studies for the expansion of Tema port three alternative port layouts have been considered: (1) expansion to the west with container berths parallel to the shore protected by a L-shaped breakwater attached to the shore, (2) similar to alternative 1 but with the container berths perpendicular to the shore protected by a detached offshore breakwater and (3) seaward extension of the port (see Figure 4 from JICA and GPHA, 2002 and Halcrow, 2010). The main differences between the alternatives are that alternatives 1 and 2 require dredging works to deepen the port basin and navigation channels whereas alternative 3 does not require dredging, because it is naturally sufficiently deep. Because layout alternative 3 is at deeper water, the expected costs for breakwater construction are higher than for the other alternatives. The fill for the land reclamation in alternatives 1 and 2 can partly be obtained from the dredging works, but the dredged volumes are considered insufficient for the entire fill. For alternative 3 the entire fill for the land reclamation needs to be obtained from sources on land or further offshore.

Alternative 1 was recommended by JICA and GPHA (2002) as the most desirable alternative based on the criteria and scores presented in Table 2. However, Halcrow (2010) argues that the comparison is unfair to alternative 3, because (a) the increased capacity in terms of ship size of alternative 3 due to the larger depths is not reflected in the cost index in Table 2, (b) it is not likely that there is any difference in the quality of the berths and in terms of calmness of the water and (c) there is no substantial difference between the schemes in terms of future development. Instead, Halcrow (2010) recommends alternative 3, because it leaves the area seaward of the existing container yard for future development and involves less dredging. The latter makes the investment estimate much more reliable, because the availability of sediment sources offshore of Tema is uncertain.

Environmental considerations are not explicitly mentioned in the comparison of alternatives. All alternatives get equal scores on the criterion “Harmonization with environment” whereas at first sight the environmental impacts of alternative 3 seem to be much less than the other alternatives. Firstly, alternative 3 involves much less dredging works than the other alternatives. Secondly, alternative 3 leaves the coastal zone west of the existing port unaffected. The coastal zone is likely to offer more habitat richness and biodiversity than the zone offshore of the existing port, because it is less homogenous and less affected by present ship traffic. Thirdly, alternative 3 leaves space for the (optional) restoration of the Sakumo II lagoon. Although the Sakumo II lagoon is not directly related to the port development, it leaves the option for ecosystem and biodiversity restoration of this Ramsar site open. Hence, from an ecosystem perspective alternative 3 would have been more desirable than the other alternatives.

Despite the above considerations and Halcrow's recommendation, the port layout that eventually has been selected for construction (see Figure 3) is similar to alternative 1, but extends even farther to the west, covering the entire coast from the present port breakwater to the outlet culvert of the Sakumo II lagoon. The motivation for this choice could not be tracked from the studied documents. In the Social and Environmental Impact Assessment (ESIA) of the Tema port extension (SAL Consult Ltd, 2015) only this selected layout has been considered and compared to the no action (or “do-nothing”) option. Hence, alternative, more ecosystem based layouts have not been explicitly weighed in terms of their environmental impacts. Instead, the SEIA focused on a comparison of alternatives in terms of structures and material for the selected layout, which is one level lower in our framework.

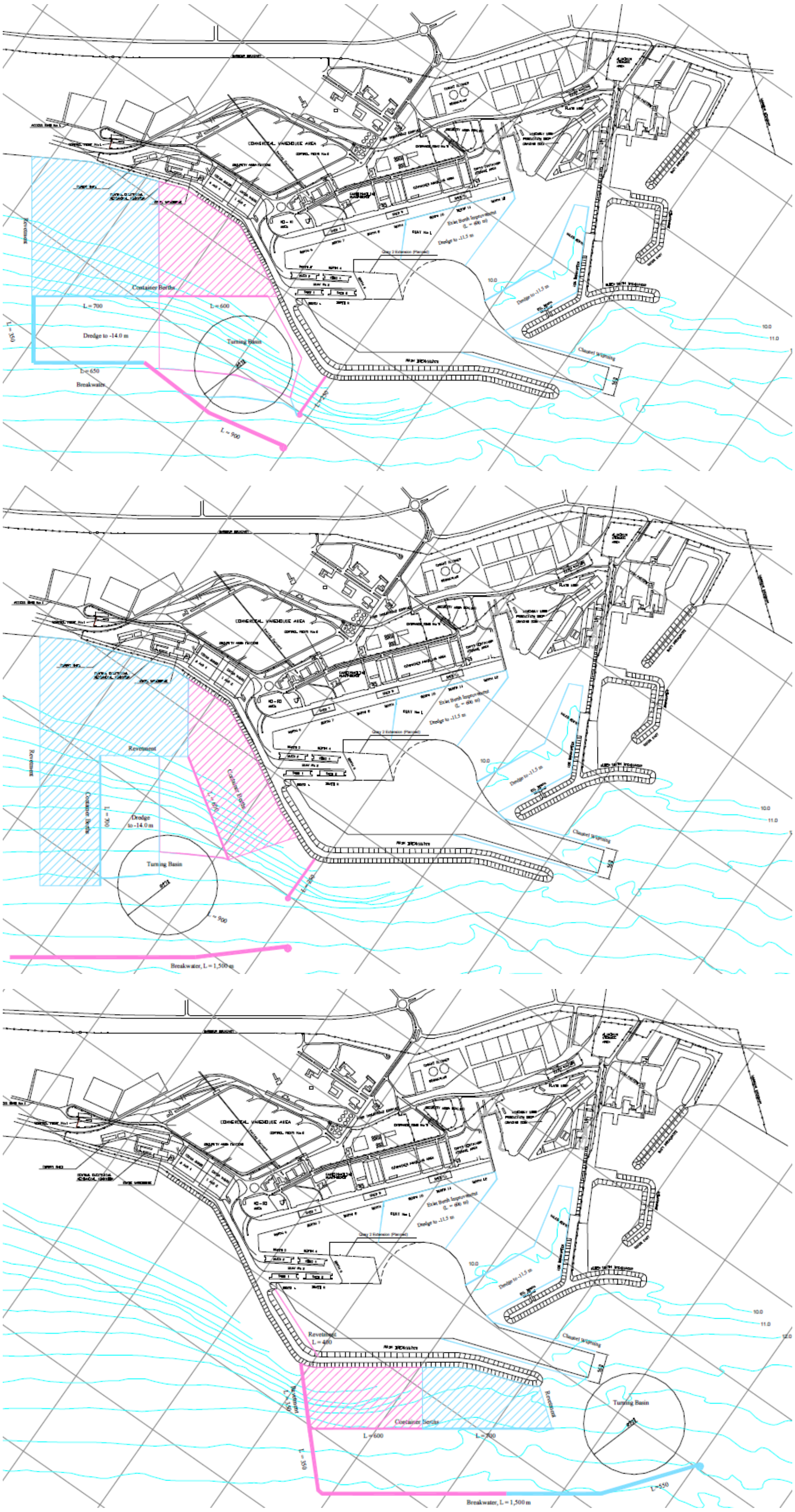

Figure 4: Alternative port layouts considered for the Tema port expansion, from top to bottom alternative 1, 2 and 3 (source: JICA and GPHA, 2002)

	Alternative - 1	Alternative – 2	Alternative - 3
Quality of Berths	***	***	**
Calmness of water	***	***	**
Navigational safety	***	***	**
Future Development	***	***	**
Disturbing existing port facility	***	***	***
Harmonization with environment	***	***	***
Cost Index	100	112	107

Note: *** Good **Fair *Poor

Table 2: Comparison of Tema port expansion layouts (source: JICA and GPHA, 2002)

4.4 Level 4: Selection of port structures and materials

At the lowest level in the *ecosystem based port design hierarchy* the layout has been fixed, which narrows down the design choices to the type of structures and materials for the port infrastructure. In the feasibility and SEIA studies for the Tema port expansion different alternatives are considered for the type of port structures in terms of breakwaters and quay walls (Halcrow, 2010; SAL Consult Ltd., 2015). For the breakwaters rubble mound breakwaters are compared to caisson breakwaters. The comparison is primarily based on functional, operational and economic considerations such as structural integrity, material needs, ease of construction and costs of construction and maintenance (SAL Consult Ltd., 2015). Ecosystem based considerations such as the potential to create more heterogeneity and niche habitats on the hard substrate as well as nature based alternatives for the "hard" engineering solutions have neither been included in the generation nor the evaluation of alternatives.

For the quay wall structures block wall, piled pier, caisson and cofferdam alternatives are considered in the SEIA (SAL Consult Ltd, 2015). Those alternatives are qualitatively evaluated in terms of buildability, durability, local experiences, availability of local equipment, adaptability to local soil conditions, wave reflection and construction costs. Again, ecosystem based considerations, such as chemical leeching from structural materials and reinforcement of existing functions are neither included in alternative generation nor the evaluation. Therefore, potential opportunities for increased habitat complexity (Mercader et al., 2017), the use of alternative materials such as ECOncrete© (Perkel-Finkel et al., 2017) and other options described in Section 2.4 may have been missed. It is not said that the inclusion of such alternatives or the incorporation of an ecological evaluation criterion would have resulted in other choices for the types of structure and materials. However, it would at least have been an explicit consideration in the design process and decision making.

5 CONCLUSIONS

Based on the reviewed documents of Tema port expansion as well as interviews with local stakeholders we conclude that – at all hierarchical levels of the *ecosystem based port design hierarchy* – the alternative generation and, hence, the decision making process for the Tema port expansion is primarily informed by economic and functional requirements rather than ecosystem based considerations. Although "harmonization with the environment" is an explicit criterion in the scoring and selection of port lay-out alternatives in the feasibility stage (JICA and GPHA, 2002), the scores on this criterion are hardly underpinned and debatable. The Social and Environmental Impact Assessment (SEIA, SAL Consult Ltd, 2015) does consider environmental impacts, but at that stage most of the planning and design decisions were already made and the number of substantially different design alternatives was limited. As a result, options for avoidance and reduction of environmental impacts may have been missed, and focus shifts to offsetting of environmental impacts.

Although ecosystem based considerations have barely been accounted for in the planning and design documents of Tema port expansion, this does not necessarily imply that ecosystem based alternatives would have been possible at every level of the hierarchy. The Tema case shows that realistic ecosystem based alternatives for the port development (level 1) and site selection (level 2) to meet the Ghanaian transport capacity requirements are barely available in this specific context. Therefore, the design freedom is limited to levels 3 (port lay-out) and 4 (port structures and materials). Our analysis shows that at these levels – from an ecosystem perspective – a wider range of alternatives would have been possible. However, inclusion of ecosystem based alternatives at these levels does not automatically result in more ecosystem based port implementations. Decision making is a multi-stakeholder process requiring trade-offs between different stakes and criteria. Stakeholders may assign more weight to social, economic or functional considerations than ecosystem based considerations. Therefore, ecosystem considerations may eventually not be decisive in the decision making process.

It should be noted that the identification of ecosystem based alternatives at each level of the hierarchy is strongly dependent on the environmental, social and economic context of the port development and, hence, situation specific. Hence, the alternatives identified for the Tema case may not be applicable for port developments elsewhere. Likewise, the characteristics of the Tema case also limit the feasibility of alternative options at the higher levels of the design hierarchy (i.e. level 1 and 2) whereas other case studies may have more potential at these higher levels. As the number of ecosystem based design alternatives is potentially infinite, the examples presented in this paper are by no means complete. The examples provided should be seen as inspirational alternatives to traditional port design rather than a complete overview of design options.

We believe that explicit identification and inclusion of ecosystem based alternatives as part of the decision making process of seaport planning and design, as supported by our framework, is a requirement to arrive at port developments that are (better) harmonized with nature. It may increase opportunities for environmental impact avoidance and reduction, recognition of ecosystem service opportunities otherwise overlooked (e.g. food production, tourism, flood protection) as well as transparent weighing of these opportunities in the decision making process. Although our framework is now not relevant for the implementation of the Tema port expansion anymore, we believe that the lessons learnt can be of added value for planning and design of ecosystem based port developments elsewhere.

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REFERENCES

Alemany, L.J., 2005. Marinas and commercial and fishing ports. Portus 9, 22-27.

Bakermans, B.A., Van der Hout, A.J., Wijdeven, B., 2015. Open ports for container vessels. Proceedings of the 36th IAHR World Congress 2015, The Hague, The Netherlands.

Bruun, P., 1981. Breakwater or mooring system? The Dock and Harbour Authority, Vol XLII, No. 730, pp. 126-129.

Bruun, P., 1990. Port Engineering. 4th Edition, Gulf Publishing Company, Houston.

Bruun, P., 1992. Marine terminal technology. Handbook of coastal and ocean engineering, Vol. 3 – Harbors, navigational channels, estuaries, environmental effects, J.B. Herbich Edt., Gulf Publishing Company, Houston.

Burt, J., Bartholomew, A., Bauman, A., Saif, A., Sale, P.F., 2009. Coral recruitment and early benthic community development on several materials used in the construction of artificial reefs and breakwaters. Journal of Experimental Marine Biology and Ecology 373, pp. 72-78.

De Jong, M.P.C., Weiler, O.M., Schouten, J., 2012. Open water ports – a sustainable designa approach. Third International Engineering Systems Symposium, CESUN 2012, Delft University of Technology, 18-20 June 2012.

De Vriend, H.J., Van Koningsveld, M., Aarninkhof, S.G.J., De Vries, M.B., Baptist, M.J., 2015. Sustainable hydraulic engineering through building with nature. Journal of Hydro-environment Research 9, pp. 159-171.

Dekker, R., Drent, J., Ten Horn, J., McSweeney, N., 2014. Ontwikkeling van mosselbegroeiing op strandhoofden met een Elastocoast® toplaag. NIOZ-rapport, 2014-3. NIOZ: Texel. 33 pp (In Dutch).

Diab, H., Younes, R., Lafon, P., 2017. Survey of research on the optimal design of sea harbours. International Journal of Naval Architecture and Ocean Engineering 9, pp. 460-472.

Dugan, J.E., Airoldi, A., Chapman, M.G., Walker, S., Schlacher, T., 2011. Estuarine andcoastal structures: environmental effects. A focus on shore and nearshorestructures. In: Elliott, M., Dugan, J.E. (Eds.), Treatise on Estuarine and CoastalScience. Elsevier, New York.

ESPO, 2012. ESPO Green Guide – Towards excellence in port environmental management and sustainability. European Sea Ports Organization, Bruxelles, Belgium.

Firth, L.B., White, F.J., Schofield, M., Hanley, M.E., Burrows, M.T., Thompson, R.C.,Skov, M.W., Evans, A.J., Moore, P.J., Hawkins, S.J., 2016. Facing the future: theimportance of substratum features for ecological engineering of artificialhabitats in the rocky intertidal. Mar. Freshwater Res. 67, 131–143.

GPHA, 2017. Tema Port Performance 2000-2016. http://www.ghanaports.gov.gh/publications.aspx (Accessed 7 March 2018).

GPHA, 2018. Tema Port – Our History and Future. Ghana Ports and Harbours Authority. http://www.ghanaports.gov.gh/page/15/Our-History-And-Future (Accessed 7 March 2018).

Gray JS (1997) Marine biodiversity: patterns, threats and conservation needs. Biodiversity & Conservation 6:153-175

Halcrow Engineers PC, 2010. Feasibility Study for the Ghana Ports of Tema and Takoradi. Vol 1-3., New York, April 2010.

Hevner, A.R., Salvatore, T.M., Park, J., Ram, S., 2004. Design science in information systems research. MIS Quarterly, Vol. 28, No 1, pp. 75-105.

JICA and GPHA, 2002. The development study of Ghana sea ports in the Republic of Ghana. Final report. Vol 2-4.

Lam, J.S.L, and Notteboom, T., 2014. The Greening of Ports: A Comparison of Port Management Tools Used by Leading Ports in Asia and Europe. Transport Reviews Vol 34 Issue 2, pp 169-189.

Ligteringen, H., 2012. Ports and Terminals. Delft University of Technology. Delft Academic Press.

Mercader, M. et al., 2017. Small artificial habitats to enhance the nursery function of juvenile fish in a large commercial port of the Mediterranean. Ecological Engineering 105, pp. 78-86.

Mineur, F., Cook, E.J., Minchin, D., Bohn, K., MacLeod, A., Maggs, C.A., 2012. Changing coasts: marine aliens and artificial structures. Oceanogr. Mar. Biol.50, pp. 189–234.

Nebot, N., Rosa-Jimenez, C., Ninot, R.P., Perea-Medina, B., 2017. Challenges for the future of ports. What can be learnt from the Spanish Mediterranean ports? Ocean & Coastal Management 137, pp. 165-174.

Odum, H.T. and Odum, B., 2003. Concepts and methods of ecological engineering. Ecological Engineering 20, pp. 339-361.

Paalvast, P., Van Wesenbeeck, B.K., Van der Velde, G., De Vries, M.B., 2012. Pole and pontoon hulas: An effective way of ecological engineering to increase productivity and biodiversity in the hard-substrate environment of the port of Rotterdam. Ecological Engineering 44, pp. 199-209.

Peris-Mora, E., Diez Orejaz, J.M, Subirats, A., Ibanez, S., Alvarez, P., 2005. Development of a system of indicators for sustainable port Management. Marine Pollution Bulletin 50, pp. 1649-1660.

Perkol-Finkel, F., Hadary, T., Rella, A., Shirazi, R., Sella, I., 2017. Seascape architecture – incorporating ecological considerations in design of coastal and marine infrastructure. Ecological Engineering, In Press Corrected Proof, https://doi.org/10.1016/j.ecoleng.2017.06.051.

Pachakis, D., Libardo, A., Menegazzo, P., 2017. The Venice offshore-onshore terminal concept. Case Studie on Transport Policy 5, pp 367-379.

PIANC, 2011. Working with Nature. PIANC Position Paper. www.pianc.org/workingwithnature.php (Accessed March 7, 2018).

PIANC, 2014a. Masterplans for the development of existing ports. Report N 158

PIANC, 2014b. 'Sustainable Ports' a Guide for Port Authorities. Report N 150.

PIANC, 2018. Site selection and planning for new ports and special marine terminals on greenfield sites – technical guidelines. Report in preparation.

Ray, G.C., 1988. Ecological diversity in coastal zones and oceans. Biodiversity, pp. 36-50.

SAL Consult Ltd, 2015. Environmental and Social Impact Assessment (ESIA) study of port infrastructure development, port of Tema - Revised EIS, Accra, Ghana. June 2015.

Schipper, C.A., Vergouwen, S., De Jong, M., Vreugdenhil, H., De Bel, M., Schasfoort, F., Minderhoud, S. (2015). Port of the future. Exploratory study. Deltares report.

SIGTTO, 1997. Site Selection and Design for LNG Ports and Jetties. Information Paper No. 14, Society of International Gas Tanker and Terminal Operators Ltd, London, United Kingdom.

Slinger, J.H. (Jill); Nava Guerrero, G. d. C. (Graciela) (2016) Engineering: Building with Nature 101x video #08 – Distilling Ecological Design Principles. TU Delft. Dataset. http://dx.doi.org/10.4121/uuid:20576f6c-e439-4a79-abc4-ad13742c7b48 (https://youtu.be/SCK9j2FfwJg)

Tallis, H., Kennedy, C.M., Ruckelshaus, M., Goldstein, J., Kiesecker, J.M., 2015. Mitigation for one & all: An integrated framework for mitigation of development impacts on biodiversity and ecosystem services. Environmental Impact Assessment Review 55, pp. 21-34.

Thoresen, C.A., 2003. Port designer's handbook. Thomas Telford.

Xiao Z. and Lam J.S.L., 2017. A systems framework for the sustainable development of a Port City: A case study of Singapore's policies. Research in Transportation Business & Management 22, pp. 255-262.

Zheng, Z.Z., 2015. Integrated sustainable port design framework development port masterplan. MSc Thesis, Delft University of Technology and National University of Singapore, https://repository.tudelft.nl/islandora/object/uuid%3Ac7aa0ebf-2b14-48db-9cb5-4e71ff196ff3 (Accessed March 7, 2018).

A. LIST OF SITE VISITS, EXPERT INTERVIEWS AND BRAINSTORM SESSIONS

Date	Activity	Experts involved
February 2017	Field trip Tema port	Prof Kwasi Appeaning Addo and team (University of Ghana), Jacob K. Adorkor (GPHA)
12-05-2017	Brainstorm port layout design	Martijn de Jong (Deltares), Tiedo Vellinga (Delft University of Technology, Port of Rotterdam), Heleen Vreugdenhil (Deltares, Delft University of Technology), Cor Schipper (Deltares), Arno Kangeri (Wageningen Marine Research), Poonam Taneja (Delft University of Technology), Cornelis van Dorsser (Delft University of Technology), Wiebe de Boer (Deltares, Delft University of Technology)
15-09-2017	Open interview World Wide Fund for Nature	Daphne Willems (WWF-NL)
27-09-2017	Open interview CSIR	Steven Weerts (CSIR)
24-11-2017	Brainstorm port design hierarchy	Wiebe de Boer, Jill Slinger, Arno Kangeri
08-12-2017	Research Integration Meeting	Wiebe de Boer, Jill Slinger, Arno Kangeri, Tiedo Vellinga, Daan Rijks (Royal Boskalis Westminster N.V.), Mark Koetse (VU University Amsterdam), Liselotte Hagendoorn (VU University Amsterdam), Peter van Beukering (VU University Amsterdam)
12-01-2018	Brainstorm ecological engineering designs	Wiebe de Boer, Jill Slinger, Arno Kangeri