Novel Urban Waterfront Ecosystem Services Evaluation, Monitoring and Improving Strategies

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Introduction

The urban waterfront is the interface between urban areas and their adjacent water (Timur, 2013). Urban waterfronts have historically been the hub of transportation, trade and commerce. In the 20th century, many cities evolved from a manufacturing or trade economy to a service industry economy – often abandoning their waterfronts in the process, with common environmental problems, and creating the opportunity and need to reconceive the waterfronts (Smith et al., 2012). In the early 21st century, the waterfront regeneration trend has continued, often with a broader view of restoring and improving urban waterfront ecosystem services.

Here we suggest that this contemporary and continuous trend of urban waterfront regeneration represents a fundamental change in understanding and perception of urban waterfronts from a historical commercial/industrial place, to the waterfront as a special zone where goals for sustainability and resilience inspire new waterfront developments that explicitly aim to provide multiple ecosystem services, and support the concept of urban greenways.

The Configuration of Novel Urban Waterfronts and Ecosystem Services

Urban waterfronts can be viewed and analyzed from different scales and perspectives. This article adopts 2 different scales for analyzing urban waterfronts: the district scale along the shoreline, and the scale of the construction profile perpendicular to the shoreline.

Urban waterfront configuration at the district scale

The city's urban waterfront composition at the district scale can be seen as a linear mosaic system, consisting of several to many kilometers, defined by different edge types and different adjacent land use types. We propose 2 different major characteristics to evaluate the potential of ecosystem service provisions at the district scale: waterfront shape complexity and the urban waterfront connectivity.

Urban waterfront connectivity: The waterfront area can be seen as an inherently linear element, and therefore represents the key challenges and opportunities that all greenways address: connectivity, multi-functionality, and co-occurrence of resources along waterfronts (Ahern, 1995). We propose 2 main perspectives of urban waterfront connectivity in Table 1.

Table 1. Provision of ecosystem services in different levels of connectivity

Connectivity type	High connectivity	Medium connectivity	Low connectivity
Ecological habitat connectivity	Continued natural vegetated riparian corridor without interruption. The corridor has a minimum width to support animal and fish movement.	Natural vegetated riparian corridor with several interruptions. corridor width is not enough to support the movement of some specialist species.	Fragmented vegetation with little or no connection Generally lacking enough space to support animal and fish movement.
Open space connectivity	Continuous pedestrian path / bicycle route connecting open spaces.	Pedestrian path / bicycle route with several interruptions by structures, building, etc.	Providing very little or no visitor's access.

Urban waterfront complexity: Urban waterfront complexity illustrates the heterogeneity of different composition of the waterfront area. An urban waterfront with high complexity is more likely to support multiple ecosystem services. We propose 2 perspectives of urban waterfront complexity in Table 2.

Table 2. Provision of ecosystem services in different levels of complexity

Complexity type	High complexity	Medium complexity	Low complexity
Biodiversity complexity	Variable habitat provision for multiple species	Limited habitat provision for species	Very little or no habitat provision for species
Land use complexity	Variable mixed public land use (open green space, commercial area, tourism site, etc.)	Limited types of land use with some public inaccessible areas	Homogeneous land use for non-public use (industrial, residential, etc.)

Urban waterfront configuration at the construction profile scale

The construction scale of the urban waterfront details the interface of land and water. We propose 2 major characteristics to measure overall ecosystem services, urban waterfront stability and urban waterfront flexibility.

Urban waterfront stability: The urban waterfront stability is the function of physical support in the urban access zone, planting and human activity and offer important protection from the hazards such as water erosion and wave flushing. The level of stability can be analyzed as: structure stability and hazard-resistant stability (Table 3).

Table 3. Provision of ecosystem services in different levels of stability

Stability type	High stability	Medium stability	Low stability
Structure stability	Stable structure for long lasting	Relatively stable for a period of time	Unstable and may collapse over time
Hazard- resistant stability	High resistance to wave impact and water erosion	Medium resistance to wave impact and water erosion	Low resistance to wave impact and water erosion

Urban waterfront flexibility: The flexibility of urban waterfront reflects the ability to grow plants and provide water purification, habitat provision and other ecosystem services and supports resiliency under disturbances. The level of flexibility can be analyzed in 2 different types: hydrology flexibility and biodiversity flexibility (Table 4).

Table 4. Provision of ecosystem services in different levels of flexibility

Flexibility type	High flexibility	Medium flexibility	Low flexibility
Hydrology flexibility	Multiple hydrological regulation features	Limited hydrological regulation features	Obviously lacking hydrological features
Biodiversity flexibility	Effective to support riparian habitat biodiversity	Limited biodiversity support	Very limited or no biodiversity support

The different ecosystem services of a “toolbox” of commonly used urban waterfront types are compared in Table 5. Hardened edges often have good stability but lack ecosystem services such as habitat provision and water purification features (Gianou, 2014). Natural or semi-natural edges can have high flexibility but may lack stability.

Table 5. Provision of ecosystem services in different urban waterfront types

Urban waterfront type	Structure stability	Hazards resistant stability	Hydrology flexibility	Biodiversity flexibility
Bulkhead edge	High	High	Low	Low
Rock riprap edge	High	High	Medium	Low
Gabion edge	Medium	High	Medium	Medium
Log crib edge	Medium	Medium	Medium	Medium
Vegetated geogrid edge	Medium	Medium	High	High
Branchpacking edge	Medium	Medium	High	High
Live stake edge	Medium	Medium	High	High
Natural edge	Low	Medium	High	High

Urban waterfront cultural identity
The cultural vitality of the urban waterfront is a significant cultural service among the ecosystem services – and is directly relevant to urban greenways. With the city's development history often involving the waterfront, many urban waterfronts have their unique history characteristics, which can be a strong and clear medium for the recognition of history.

Planning and design principles for novel urban waterfronts

This article proposes 3 strategies to help to achieve more sustainable and resilient urban waterfronts with the analysis of recent waterfront regeneration projects in the novel urban waterfront planning and design paradigm.

Strategy 1: Improve connectivity and complexity of urban waterfronts
Enhanced multiple habitats provision: The urban waterfront connectivity can be enhanced by reconnecting the habitat fragments separated by former development. It can be achieved by adapting/supplementing the hardened surface area as a planting area, constructed wetland, storm water buffer zone or other application of ecosystem-supporting area.

Multiple transportation integration: Different transportation routes can also be provided to enhance water access, such as bicycle and pedestrian paths. Water access can be provided, for example to support kayaks, rowboats, and other pleasure and commercial watercraft.

Multiple land use integration: In the new paradigm of waterfront planning and design, we suggest to provide high levels of access to the urban waterfront by the integration of different public land uses such as green spaces, sports fields and commercial sites along the urban waterfront to use the land more efficiently and satisfy the different needs of people. This strategy typically supports urban greenways.

The Kallang River regeneration project in Singapore shows benefits realized by improving the urban waterfront stability and flexibility. The 2.7 km long straight concrete canal has been restored into a 3.2 km sinuous, "semi-natural" river corridor. The riparian buffer areas are stabilized with bioengineering technology to accommodate the dynamic process of the river system to maintain stability and increase flexibility. The newly established riparian corridor has provided habitats for flora and fauna which have produced a 30% biodiversity increase in the park (Atelier Dreiseitl GmbH, 2013).

Strategy 2: Achieve both durability and flexibility

Structural modularization: Assembled with modularized parts, the urban waterfront can be adaptive to the changing conditions of the urban waterfront. The modularized unit is easy to install and restore if damaged. Gabion edge, cellular unit retaining edge, cellular confinement using porous plastic sheets are examples of structural modularization.

Application of porous structure: Porous structures can effectively dissipate the wave energy to improve durability, while the space between the porous structure can provide habitat for aquatic fauna and support plants to grow in the sediment between the structures. Some of the commonly used porous structures are the rip-rap, gabions and geogrid.

Integration of native plants: The roots of the native plants can enforce the edge against soil erosion to enhance stability. Plants can also provide other useful ecosystem services such as habitat provision and bioremediation. Live stake edge, live fascine edge, branchpacking edge, vegetated geogrid edge are some of the edge examples to integrate native plants (NRCS, U. 1996).

In the Harlem River Park waterfront regeneration project in New York City, Recycled tires edge (Figure 1) were proposed as an innovative alternative to a traditional gabion edge. The recycled tires are easy to find and very stable against erosion and corroding. The tires can also provide varied microclimates with their irregularly cut surfaces. Moreover, the recycled tires are highly durable, modularized structures which are easy to pile up or get replaced (Johnson, 2010).

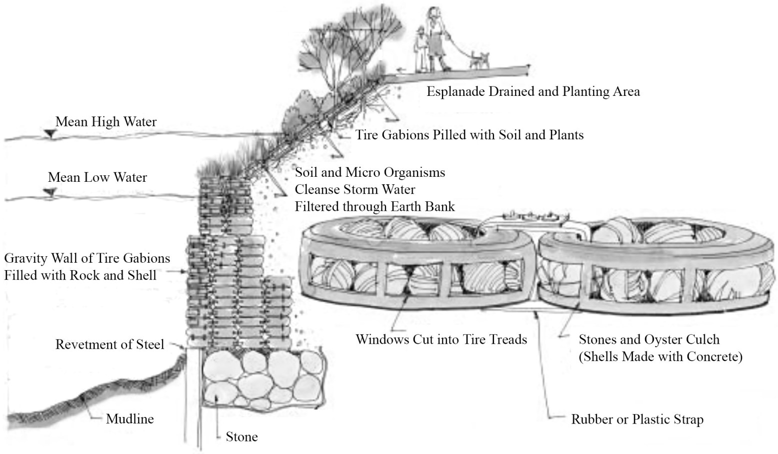

Figure 1. The proposed tire gabion edge of Harlem River Park (Johnson, 2010)

Strategy 3: Improve cultural vitality of urban waterfront

To improve the cultural vitality means to identify, understand and manage the unique character of the site and try to avoid imitating or copying from other unrelated cultural sites which may result in losing its own identity. The design style, on-site structures and facilities can be a reflection of the cultural identity of the particular city and the particular area of the waterfront. The application of native plants can also be an effective way to improve the local cultural identity as well as other ecological benefits.

The West Lake waterfront in Hangzhou, China has a history of more than one thousand years. But with the city's development, the waterfront area was facing ecosystem degradation, green space fragmentation and other problems. Since 2001, a renovation project has begun to implement to address the problems and improve the ecological, recreational and cultural functions of this World Heritage waterfront landscape. The team of the renovation project adjusted the land use around the lake to get more green spaces and relocated the institutions out of the waterfront. They also reconnected the parks together and established a continuous pathway around the lake for pedestrians and cyclists. By 2006, the open space around the lake was increased from 430 hectares to 510 hectares. And the number of tourists per year has increased by 15 million since 2001 (Xiangrong et al., 2010).

Figure 2. The open space before and after the West Lake, Hangzhou renovation project (Xiangrong, 2010)

Applying the "learning by doing" adaptive design approach in urban waterfront planning and design

To realize the tremendous potential in urban waterfronts, an adaptive design mode can be adopted by employing innovation, experimentation and rigorous "designed experimental" procedures, including monitoring and feedbacks (Kato and Ahern, 2008). Monitoring is the key to obtain effective data to measure the condition of ecosystem services (Kato and Ahern, 2008). The methods can come from related subjects research and practice such as hydrometry, ecology and sociology.

A study on the urban waterfront adaptive strategies was conducted by New York City's Department of City Planning in 2013 aiming to increase the resilience of waterfront communities. The study illustrates a 6-step evaluation process integrated with monitoring and reassessment procedures to provide a flexible and replicable process to select and adjust appropriate strategies. The process is aimed to provide a general adaptive planning and design steps for each specific planning projects or initiatives. With the adaptive design strategy, a flexible adaptive pathway can be made. Adaptive pathways can have alternative plans and the integration of periodic decision points (Burden et al., 2013).

Conclusion

Globally, urban waterfronts are evolving from rigid, single functional water resisting walls to diversified novel urban waterfronts with high levels of ecosystem services performance. The innovative novel urban waterfronts can provide multiple ecosystem functions with flexibility. Such waterfronts are highly compatible with and supportive of an urban greenway concept. A well functioning urban waterfront should also be resilient to many forms of disturbances. A comprehensive and ongoing monitoring and evaluation process of waterfront ecosystem service performance will provide constant feedback. And a "learning by doing" adaptive planning and design progress will be the way leading to a sustainable and resilient functioning urban waterfront.

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