

Review of the performance of the artificial floating island as a restoration tool for aquatic environments

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Abstract

Artificial Floating Islands (AFIs) are vegetated floating platforms used in lakes, ponds and reservoirs to enhance the aquatic environment. AFIs have four functions: 1) water purification, 2) habitat enhancement, 3) shoreline erosion protection, and 4) improved landscape features. This paper reviews the performance of AFI. Although AFI can be found in many countries (e.g. China, England, Germany, Japan, Korea, and Taiwan) they are most prevalent in Japan where more than 70,000 m² of AFI structures exist. AFI provides critical habitat for birds and provide important substrate for spawning fish. However, water quality enhancement is their most important feature, especially in Asia where their installation over large surface areas (10 to 30%) of lakes and reservoirs help mitigate the effects of eutrophication. Their shade helps to decrease phytoplankton, while their vegetation helps in nitrogen reduction. The crucial advantages of AFIs are that they float and adapt to water level fluctuations in reservoirs and the reduce predation risks by providing safe, inaccessible refuges for nesting birds.

Introduction

Interest in the restoration of aquatic environments has been increasing worldwide. Artificial Floating Islands (AFIs) are vegetated platforms used to augment or enhance aquatic features

found in lakes, ponds and reservoirs. AFIs have four major functions that include: 1) the enhancement of water quality, 2) habitat enhancement, 3) landscape features and 4) reductions in shoreline erosion (Nakamura et al., 1999a), and 4). AFIs can improve water clarity by reducing turbidity associated with shoreline erosion and by reducing algal blooms. They can also provide spawning substrate and cover for fish as well as nesting and sanctuary habitat for water fowl and birds. They are especially useful in reservoirs or lakes that suffer from shoreline erosion caused by waves and fluctuating water elevations. AFIs provide managers options to add or increase habitat diversity to accent the landscape and attract desirable species.

As early as 1900, AFIs were installed in New Hampshire (USA) lakes to provide nesting habitat for birds (Gaviidae) (AFI study group, 2000). The first floating structures in Japan were installed in the early 1920's and were constructed of fascines; stick bundles that were installed to provide fish spawning structure (Hirose, 1997). Lake managers began to recognize their usefulness and resulting designs became more complex and durable. In 1979, the Germans started using a modern AFI design, called Schwimmkampen; meaning 'floating campus' (Hoeger, 1988). In the early 1980's, Japan led the way in the design and testing of large AFIs in Lake Biwa. A great deal of information was learned to improve their structural design and biological benefits.

The International Conference of Lakes-Kasumigaura 95 was hosted by Japan in 1995 and resulted in increased interest in this technology (Nakamura et al., 1995; Song et al., 1995; Terazono et al., 1995). Since then, increased interest and associated manufacturing companies have resulted in more than 70,000 m² of AFIs being installed on Japanese waters (AFI study group, not published). This technology has also spread to Korea, Australia, Canada, China, India, Germany, Spain, Taiwan, UK and the USA (Boutwell, 1995; Mueller et al., 1996, Lee et al., 2001).

While AFIs have become a common environmental feature in many places of the world, there are few papers in English that describe the technology or associated research from Japan. The purpose of this paper is to provide a brief historical perspective of the technology and describe recent technological advances in understanding the benefits that can be derived from AFIs.

Design and Structure

AFI designs can be divided into two categories; "wet" and "dry" (Figure 1) (Nakamura and Shimatani, 1999b). Wet

structures are designed to have the vegetative root mass extend into the water column while dry structures have the root mass contained in an enclosure. Wet AFIs can be divided into three groups; those with a large supporting frame, those constructed without a supporting frame and, lastly, other design themes. The most common (70%) AFI in use today is a wet structure that has a structural frame which allows the vegetation's root mass to extend into the water. AFIs utilizing the dry design comprise nearly 20% of the structures in use and are typically constructed of a floating shell of concrete. The remaining 10% fall into the "wet without a frame" or other design themes (anonymous, 1999).

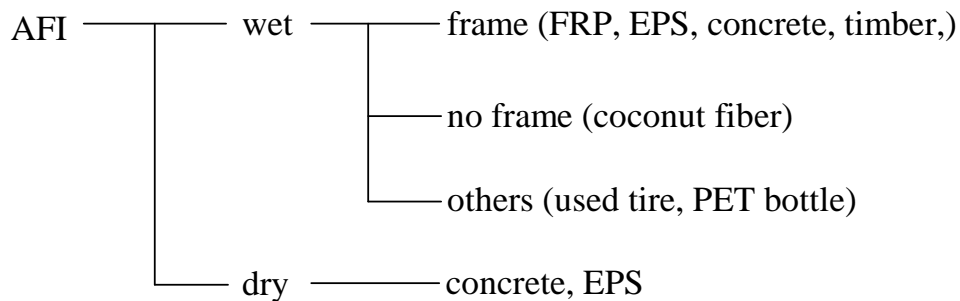


Figure 1. Structural classification of AFIs



Figure 2. Dry-concrete AFI in Lake Kasumigaura (left) (photo: Maeda Environmental Art), Wet-without-frame AFI with coconut fiber plant base (right) (Komoro regulating pond)



Figure 3. AFI in Lake Kasumigaura (wet with frame)

Dry AFIs (Figure 2, left) are decreasing in popularity due to high construction cost and the absence of water quality attributes. Dry-concrete AFI are generally large and can be planted with mature trees, shrubs and large terrestrial plants. When combined with small wet AFI, the result can create a more diversified landscape that is particularly attractive to birds (Terazono et al., 1995). Wet AFIs without frames (Figure 2, right) are often constructed of coconut fiber mats and floatation bladders bound together by polypropylene rope (Sato and Ihara, 2003). This design is gaining popularity due to its softer appearance and lower construction cost. Framed AFI (Figure 3) can be constructed of several materials. Frames can be built with natural or synthetic fiber, wood, reinforced plastic, stainless steel wrapped with polystyrene, polystyrene alone and with urethane and concrete. Other designs have incorporated the use of used automobile tires filled with polystyrene and coconut vegetation surrounded with plastic tubing. These structures are generally small but are cost effective (50 USD per m²) (Mueller et al., 1996). Some citizen groups have made AFI using plastic bottles (Anonymous, 1999) and recently, researchers have reported designs that support submerged plants (Shimada et al., 2007).

Coconut fiber is the most common material used to support vegetation but other materials have also been successfully used such as urethane foam used for hydroponics, polystyrene beads, fish nets and even soil.

AFIs are generally constructed singly or in multiple cells that are joined together. Individual cells normally measure 2-3 m in length and can be triangular, rectangular or square. Nowadays AFIs can be aesthetically designed depending upon their purpose (Figure 2, right). Structural integrity is quite important, especially for structures subjected to high wind or wave action. The Japanese have developed specific design recommendations for AFIs subjected to these types of natural forces (AFI study group, 2000; Sato and Ihara, 2000).

Ecological Function

Research conducted on AFIs (~1000 m²) installed on Lake Kasumigaura has provided some very compelling information regarding the environmental merits of these structures (Figure 3) (Nakamura et al., 1995; Nakamura and Shimatani, 1997a; Nakamura et al., 1997b; AFI study group, 2000). Vegetation originally (1993) planted on the Lake Kasumigaura AFIs consisted of water oats (*Zizania latifolia*), cattails (*Typha*

latifolia), *Schoenoplectus triangulatus*, bur reed (*Sparganium erectum*), yellow iris (*Iris pseudacorus*) and common reed (*Phragmites australis*). The vegetative community dramatically changed within three years, being dominated by common reed followed by water oats, yellow iris, *Polygonum thunbergii* and 17 other plant species.

The resulting plant community was lush. The average dry standing crop for the AFIs was 5.0 kg/m; however, when common reed dominated the community, standing crop exceeded 8.7 kg/ (Nakamura et al., 1997b). The average density of common reed was 424 shoots/m² which was three times denser than natural shoreline communities (~150 shoots/m²).

Fish also benefited from the Lake Kasumigaura structures. Overhead and interspaces within the root system provided habitat for seven fish species, the majority were bluegill (*Lepomis macrochirus*), rose bitterling (*Rhodeus ocellatus ocellatus*), topmouth gudgeon (*Pseudorasbora parva*) and *Tridentiger brevispinis*. Fish samples averaged 267 fish compared to only one taken from control areas (Nakamura et al., 1997b). AFI samples were dominated by yearling fish suggesting these habitats provide important cover for juveniles. Likewise, predatory fish are attracted to these structures because of the potential food source and can be more easily harvested (Mueller et al., 1996.) In Lake Biwa, 85 million fish eggs (56,600 eggs/m²) were observed under the AFIs illustrating their use by spawning fish (Nakayama, 1986).

Bird use on AFI's has been well documented (e.g., Giroux, 1981; Getz and Smith, 1989; Hiraoka, 1996; Momose et al., 1998). Great reed warblers (*Acrocephalus arundinaceus*) and common moorhens (*Gallinula chloropus*) nest on AFIs on Lake Kasumigaura. The spot-billed duck (*Anas poecilorhyncha*), little grebe (*Tachybaptus ruficollis*) and common coot (*Fulica atra*) also nest on AFIs installed at other Japanese locations (Momose et al., 1998).

Aquatic vegetation is critically important for water fowl. "Wet" AFIs support emergent aquatic vegetation which provides food, cover, resting and roosting habitat. Structures having a "dry" or "wet without frame" design supports far fewer water fowl (Momose et al. 1998). The "wet without frame" AFI structures are often inadequate to support some types of aquatic plants that are desirable to water fowl and are generally smaller in size.

Size, placement and space are important considerations when attempting to attract bird use. Giroux's (1981) suggested two major factors to consider: 1) AFIs should be designed with a surface area greater than 1000 m² and 2) they should be placed at

least 170 m from shore. Adequate space is an important factor in nesting success due to territorialism, predation and disturbance factors. Proper planning and placement can greatly improve opportunities for nesting success, especially for fluctuating reservoirs where nesting habitats are either absent or greatly limited.

Water quality

Water quality enhancement is one of the most important benefits realized from AFI. Boutwell (2002) identified a reduction of $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$, K, and total suspended solids from water collected underneath AFIs dominated by cattail (*Typha* spp). Chang (2006) studied the specific growth rate of 20 aquatic plant species and reported on the nutrient absorptions characteristics of three. Nakamura and Shimatani (1997a) studied changes in water quality caused by AFIs using experimental test cells which measured 4m by 4m in size. Treatment cells contained an AFI that covered 25% of the cell's surface area and AFIs were absent in control cells. They reported summer algal blooms occurred in the control cells but not in the cells that contained AFIs. Summer phytoplankton densities were ~10 times greater in the control cells than in the AFI cells (Figure 4). Water quality improvement occurred only during the summer and not during the winter. Shading appeared at least partially responsible for this improvement (Nakamura and Shimatani, 1997a).

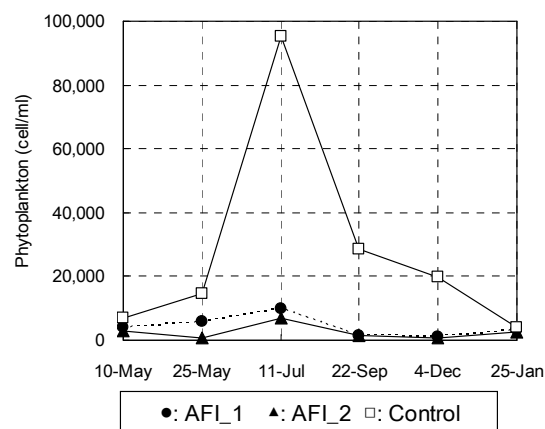


Figure 4. Cell number of phytoplankton (AFIs and control)

Oshima et al. (2001) tried to distinguish the effect of shade from other possible factors. They prepared three test cells (4m wide x 6m long x 2m depth). One cell contained a

vegetated AFI that covered 33% of the surface area, the second had a similar area (33%) covered with just plywood, and the third was the control with no shading (Figure 5). They found that both the AFI and plywood treated cells reduced phytoplankton (chlorophyll a); however, nutrients, particularly nitrogen, were only reduced in the AFI cell (Figure 6). While shade impacted phytoplankton production, floating vegetation reduced nutrient concentrations which did not occur with simple shading.

The Upper Tone River Management Office continued Oshima's research but reduced (8.3%) the percentage of vegetative cover used. Two years of experimentation resulted in the development of a regression curve showing the relationship of surface area of vegetation to the percentage decline in chlorophyll a (Figure 7) (Nakamura, 2003 [from the unpublished data of The Upper Tone River Management Office]).

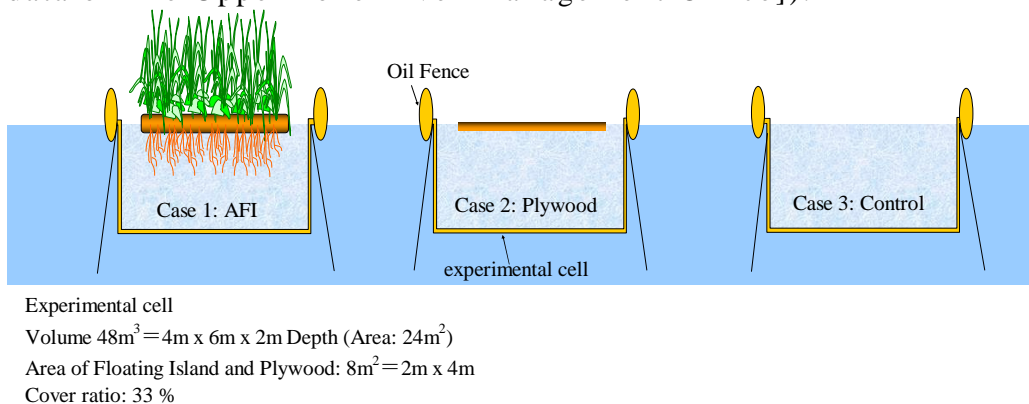


Figure 5. Schematic view of experimental cells (Ohshima et al. 2001)

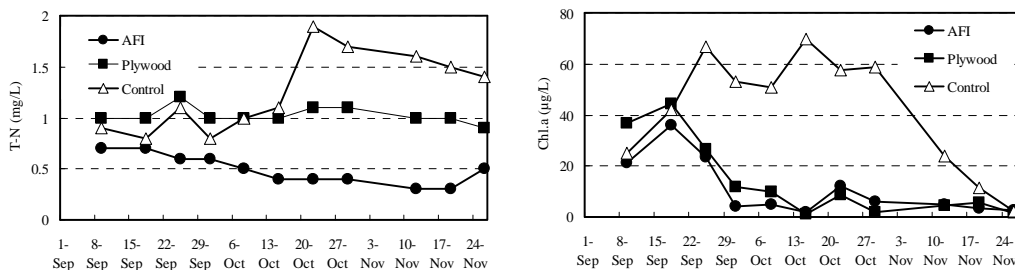


Figure 6. Total nitrogen and chlorophyll a data for the AFI, plywood and control cells.

Recently, Shimada et al. (2007) developed two kinds of AFIs designed for emergent and submerged plants, respectively. They covered 10% of the water's surface with AFIs in a mesocosm. Initially, the water was turbid but a week later it had

cleared. Both AFI types succeeded in creating a “clear water state” (Scheffer et al., 1993). After two month, natural vegetation became established on the lakes bottom due to increased solar penetration. Within a year, submergent vegetation extended through 30-40% of the water column. This suggests improvements in water clarity caused by AFIs may trigger the establishment and expansion of natural vegetation and minimize the need for expansive AFI coverage.

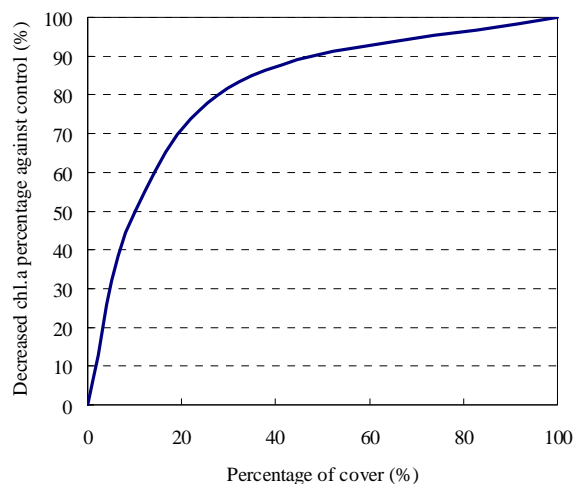


Figure 7. Percentage of AFI cover versus decreased chlorophyll a percentage against control condition

Conclusion

AFIs are being used in Japan and other countries to improve water quality and enhance aquatic environments. To provide significant improvement in water clarity and reduce algal blooms it is generally necessary for AFIs to cover 10 to 30% of water surface. Shading plays a significant role in the reduction of phytoplankton; however, AFI supported vegetation which also absorbs nutrients. AFIs are highly useful in reservoirs or lakes that are subject to significant water level fluctuations which prevents vegetation from establishing. They are also practical in small ponds where a large proportion of the surface can be covered. AFIs provide a valid approach for attracting and enhancing habitat for nesting birds and providing some fish species spawning habitat and cover for their young.

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