# Chapter 11
# Green Aquaculture: Designing and Developing Aquaculture Systems Integrated with Phytoremediation Treatment Options

**Guy R. Lanza, Keith M. Wilda, Sushera Bunluesin, and Thanawan Panich-Pat**

**Abstract** An increase in aquaculture for global food production has been one response to the sharp reductions of the stocks of aquatic species used as a source for traditional fishing methods. Phytoremediation offers an environmentally compatible approach that can be quickly integrated into existing aquaculture systems to provide management of contaminants. The scenarios of Integrated Aquaculture–Phytoremediation systems (IAPS) provided in this chapter are not intended to be all inclusive but rather serve as selected examples of potential applications. Appropriate IAPS will be highly site specific and will depend on local conditions including geomorphology, water sources, levels of ambient soil and water contamination, the aquatic species under aquaculture, and the type of culture system used. The IAPS design must provide a good balance that insures both the removal of excess nutrients and other contaminants and an adequate supply of nutrients to support the growth of

"*Can you help us get clean water*?" (Woman in TayPhong village, Vietnam following the loss of all of the fish in the village aquaculture pens in 2006 following a toxic spill in the Song Lan River.)

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the aquaculture products. IAPS can greatly enhance the global production of plant and animal food particularly in developing countries with warmer climates and highly diverse plant communities. IAPS that effectively removes snail-vectored parasites (e.g., fish-borne zoonotic trematodes) are especially desirable because snails are often cultured for food in aquaculture systems along with fish. The inclusion of carnivorous plants (e.g., *Utricularia* sp.) in IAPS may offer one solution. *Utricularia* sp. inhabiting wet soils and water are known to actively trap and consume aquatic animals, and it may be possible to use carnivorous plants to remove immature snails, snail eggs, miricidia, and cercariae as a treatment option in IAPS.

**Keywords** Phytoremediation • Aquaculture • Food security • Soil and water contaminants • Global food production • Snail-vectored diseases • S.E. Asia Aquaculture

## 11.1 Introduction

Increased demand on traditional global fisheries coupled with ocean contamination, altered patterns of aquatic species distribution due to climate change, El Nino effects, and altered predator prey relationships has raised international concern about sharp reductions in the stocks of available fish and other aquatic food species. One response has been the increased development of aquaculture systems to produce animals and plants for food. A major challenge confronting the growth of aquaculture activities is the increase in biological and chemical contamination associated with aquaculture to produce food.

The primary aim of this chapter is to encourage the development and use of phytoremediation options appropriate for treating and improving the soil, sediment, and water quality associated with aquaculture systems. Phytoremediation offers an environmentally compatible approach that can be quickly integrated into existing aquaculture systems and provide effective management of contaminants during aquaculture operations.

Phytoremediation offers an excellent array of plant–microbe choices that can be matched to a site-specific water quality problem in aquaculture. Matching the appropriate plant or plant community to chemical and biological contaminants can play a major role in conserving and protecting soil and water. Integrating phytoremediation options with various aquaculture systems can serve as a major tool to achieve cost-effective, low energy treatments that can support sustainable aquaculture production on a global scale.

The high diversity of plant species and their associated rhizoflora, and the favorable climate and long growing seasons typical of semitropical and tropical regions make phytoremediation an attractive and practical option in many developing countries. Although this chapter will focus on fish aquaculture in tropical systems, many aspects of the basic design features presented here could be applied to facilities in other climates and to the production of other organisms including crustaceans, molluscs, reptiles, and plants.

The approach and selected scenarios of integrated aquaculture–phytoremediation systems (IAPS) provided in this chapter are not intended to be all inclusive but rather serve as selected examples of potential applications. Appropriate IAPS will be highly site specific and will depend on local conditions including geomorphology, water sources, levels of ambient soil and water contamination, the aquatic species under aquaculture, and the type of culture system used. Sustainable IAPS will require interdisciplinary collaboration between local farmers, agriculture and fisheries scientists, engineers, and government officials.

## 11.2 The Global Aquaculture Industry

Current aquaculture production is on the increase representing the fastest growing sector in global livestock production [1]. The global aquaculture industry contributed 43% of all aquatic animal food for human consumption in 2007 (e.g., fish, crustaceans, and molluscs, not including mammals, reptiles, and aquatic plants) and is expected to grow further to meet the future demand. Freshwater ponds and tanks were the source for 60% of the world aquaculture production in 2008 (56% by value), despite only using 3% of the planet's water. The rapid growth noted in the production of carnivorous species including salmon, shrimp, and catfish has been driven by globalizing trade initiatives and the positive economics of larger scale intensive farming approaches [2].

The impact of climate change on future food supplies and global food security is uncertain and fisheries activity will undoubtedly face some effects influencing the sources of protein from fish and other aquatic species. Fish are an important source of protein for a substantial proportion of the world's population [3]. A portion of 150 g of fish can provide about 50–60% of an adult's daily protein requirements. In 2010, fish accounted for 16.7% of the global population's intake of animal protein and 6.5% of all protein consumed. Moreover, fish provided more than 2.9 billion people with almost 20% of their intake of animal protein, and 4.3 billion people with about 15% of such protein. Fish proteins can represent a crucial nutritional component in some densely populated countries where total protein intake levels may be low [4].

The current trend towards enhanced intensive systems with key monocultures remains strong and, at least for the foreseeable future, will be a significant contributor to future supplies. Dependence on external feeds (including fish), water and energy are key issues. Some new species will enter production and policies that support the reduction of resource footprints and improve integration could lead to new developments as well as reversing the decline evident in some more traditional systems [2].

## 11.3 Aquaculture in Southeast Asia

Aquaculture in Asia represents over 80% of total global production [4], and the total quantity of fish is projected to reach more than 95.6 million tons by 20,130 [5]. Southeast Asia has seen a significant increase in aquaculture beginning in the 1990s [6]. Aquaculture represents a major component of the food security and overall economies of several countries in South East Asia [7] including Thailand, Vietnam, and the Philippines. Thailand and Vietnam in particular are increasing their aquaculture activities in response to both an increasing global market and local demand accompanied by a leveling off of the yield from capture fisheries. The development of freshwater aquaculture in the Philippines, associated environmental impacts, and relevant environmental regulations and regulatory bodies was recently reviewed by Legaspi et al. [8]. They described the complex relationship between aquaculture and water quality and provided data from studies on Lake Mohicap to illustrate the potential role of paleolimnology as a tool to help achieve a more ecologically sustainable lake-based aquaculture in the Philippines.

Freshwater aquaculture in Thailand and Vietnam is mainly for domestic consumption and provides a good protein source for local use and also bolsters local food security. Small-scale freshwater aquaculture is currently providing the rural poor with high quality protein food for local consumption. Brackish water aquaculture can produce profitable products for both in-country use and export from both countries [9].

Freshwater aquaculture, mainly pond and rice-field culture, has been practiced in Thailand for more than 80 years. In 2003, total production from freshwater and brackish water aquaculture in Thailand was approximately 320,000 and 450,000 tons, respectively. The main freshwater species cultured were Nile tilapia (*Oreochromis niloticus*), hybrid catfish (*Clarias macrocephalus* X *C. gariepinus*), silver barb (*Barbodes gonionotus*), giant river prawn (*Macrobrachium rosenbergii*), and snakeskin gourami (*Trichogaster pectoralis*). The main brackish water-cultured species were giant tiger prawn (*Peneaus monodon* ), whiteleg shrimp (*Penaeus vanamei*), green mussel (*Perna viridis*), blood cockle (*Anadara* spp.), and oyster (*Crassostrea commercialis*). At present, more than 50 freshwater aquatic species have been cultured [9].

Nhan et al. [6] provides a detailed description of the general operation and basic economics of integrated freshwater aquaculture, crop, and livestock production using Integrated Agriculture–Aquaculture (IAA) farming systems in Vietnam. Madsen et al. [10] has studied the freshwater snail populations in Asia and provides an excellent description of the snail disease vectors including those found in integrated fish-livestock ponds in common use by families in Vietnam [10–12]. The integrated systems described by Dung et al. [12] consist of a garden (Vaun), a fish pond (Ao Ca), and a cattle shed (Chuong) and are referred to as family VAC ponds (Fig. 11.1).

Recognizing the potential of aquaculture, since 1999, the Vietnamese government promoted diversification in agriculture, aiming to reduce the share of rice to the total agricultural output value while increasing the contribution of aquaculture

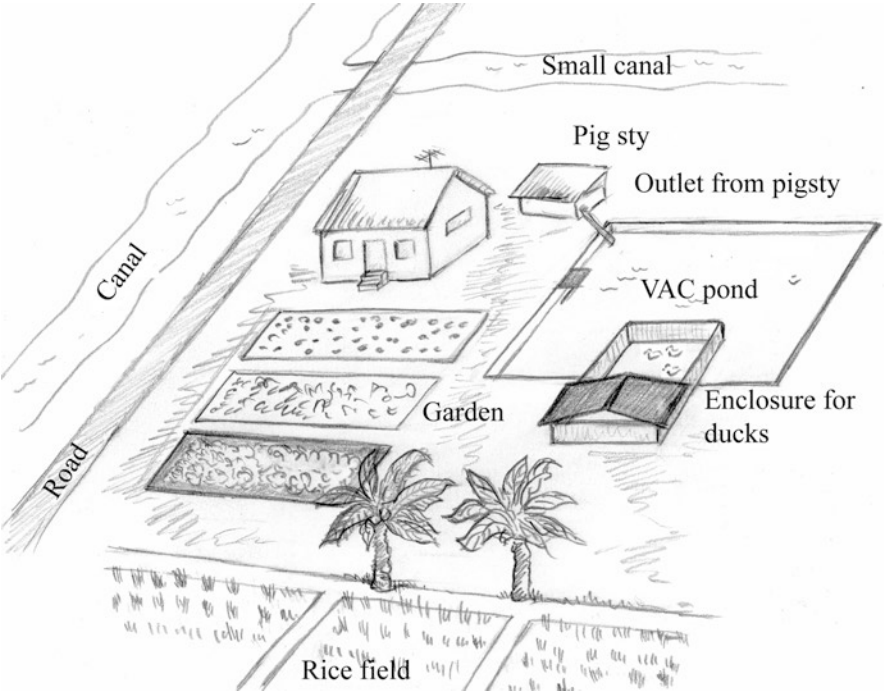



**Fig. 11.1** Schematic representation of a VAC pond (Dung et al. [12], with permission of Elsevier)

to economic growth and poverty reduction [13–15]. In this context, stimulating integration between fish, shrimp/prawn, fruit, livestock, and rice production on the same farm, further referred to as integrated agriculture–aquaculture (IAA) systems, is expected to contribute to agricultural diversification and enhance its sustainability. In Vietnam, IAA-farming has been promoted through mass organizations such as the Vietnam Gardening Association and Government Agricultural Extension Agencies [6].

An important characteristic of IAA-farming is the recycling of nutrients between farm components [16, 17]. Through nutrient recycling, IAA-farming allows intensification of production and income, while reducing environmental impacts [18–20]. Intensive export-oriented *Pangasius* sp. culture in both cages and ponds is characterized by large nutrient flows supported by the use of off-farm feeds and water exchange making local nutrient recycling problematic [21–23]. Moreover, the industrial scale of the business and its sensitivity to fluctuations in global trade make it risky and the domain of the resource-rich [24]. IAA-farming in contrast appears to be a realizable approach for diversification of rice production whereby synergism between on-farm components can be realized and whole system productivity optimized rather than that of individual enterprises [18, 25].

The potential integration of farm components and attainable intensification levels of IAA-systems are in part determined by the biophysical setting and the farmer's aspirations and decisions [26, 27]. In Vietnam, the benefits of traditional VAC (garden-pond-livestock)-integrated systems [13–15] have been widely reported and recent studies have investigated IAA commercial orchard and fish production systems [6].

In the Mekong delta, freshwater IAA-farming is commonly practiced in the central region, where soil and hydrological conditions are favorable for aquaculture. Development agencies have tended to promote a rather standardized IAA-system for the region in a "conventional, linear" approach (cited in [28]). Within the central zone of the delta, however, different agro-ecologies exist and market opportunities for farming inputs and outputs differ. In particular differences between rural and peri-urban areas are likely and might be expected to have an impact on optimal forms of IAA. In Northeast Thailand, Demaine et al. [29] found that location relative to urban centers was more important than agro-ecology in determining farmer attitudes and any likelihood of intensification. Better market accessibility in peri-urban areas and access to nutrients often stimulates intensification of aquaculture compared with more rural areas [30], allowing IAA-farming to raise income and to produce cheap food for urban consumers [18].

## 11.4 Potential Designs of Integrated Aquaculture–Phytoremediation Systems

### *11.4.1 Chemical and Biological Contaminants*

Sources of water used to supply aquaculture systems are often contaminated with organic and inorganic contaminants and disease causing microorganisms. For example, one major environmental challenge evident in many aquaculture systems in Southeast Asia and other areas of the world is the presence of freshwater snails that vector human and livestock diseases. Some aquaculture systems follow a polyculture approach that simultaneously produces fish, snails, and other aquatic food species for human consumption. Snails that are intermediate hosts of fish-borne zoonotic trematodes are of special concern in VAC ponds and other types of aquaculture systems. Dung et al. [12] provided an excellent description of the distribution of freshwater snails in family-based VAC ponds and associated water bodies with special reference to the intermediate hosts of fish-borne zoonotic trematodes in Nam Dinh Province, Vietnam.

In addition to the human and livestock health threats from aquatic species infected with chemical contaminants, parasites, and other pathogens, reduced marketability of fishes, snails, and other aquaculture products harboring disease organisms warrants control efforts to reduce contamination in aquaculture systems.

## 11.5 Aquaculture Systems in Vietnam

Figure 11.1 provides a schematic representation of a VAC pond in Vietnam [12]. High levels of nutrient pollutants (e.g., nitrogen and phosphorus) from both external and internal sources are of particular concern. Standard operations used to culture aquatic plants and animals for human and livestock consumption typically contribute additional contaminants and pathogens as waste products through the use of water contaminated with biological and chemical contaminants. These contaminants enter the aquatic food web supporting aquaculture operations and can accumulate in fish, snails, and other aquatic food sources. The lower water quality that results from the contamination contributes to both reduced overall yield of product and increases the risk of contaminated product unfit as human and livestock food sources.

Figure 11.2 presents pond nutrient flows in an integrated aquaculture, crop, and livestock system (IAA-farming) in the Mekong Delta of Vietnam [6]. Low, medium, and high pig waste nutrient input to fish farming—fruit production systems are presented as examples. The main motivations for practicing IAA-farming included increased income and food for home consumption from available farm resources while reducing environmental impacts. Fear of conflicts from the use of pesticides was given as one reason that some farmers chose to not use aquaculture.

## 11.6 Protocol for Integrating Phytoremediation with Aquaculture Systems

### *11.6.1 Assessing Water Quality*

The first step in the development of an effective integrated aquaculture–phytoremediation system is a local water quality assessment. Major water quality problems resulting from typical freshwater pond and stream aquaculture systems are listed in Table 11.1. Increased total suspended and dissolved substances, increased biochemical oxygen demand, dissolved oxygen depletion, and increased and excessive phytoplankton which can include toxic blooms are of particular concern. Table 11.1 also lists specific contaminants in typical aquaculture systems including unionized ammonia, nitrates and nitrites, heavy metals/metalloids, (e.g., As, Al, Cd, Cu, Pb, Zn), organics (malachite green, pesticides, algicides, herbicides, petroleum hydrocarbons), and microbial pathogens and parasites (bacteria, viruses, protozoa, trematodes, cestodes, nematodes). Some of the parameters in Table 11.1 can be estimated on-site using portable field-testing kits while others will require lab testing off-site. Paleolimnology can be used to characterize the water quality history of lakes and medium to large ponds serving as aquaculture systems [8].

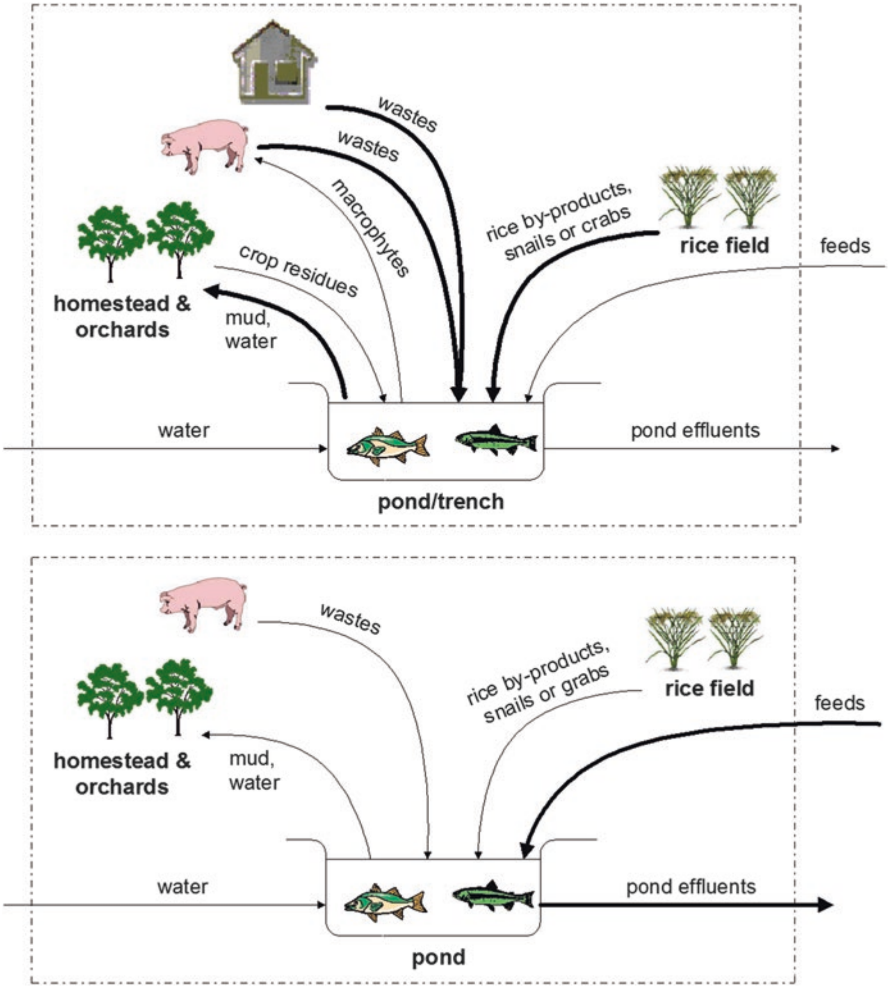



**Fig. 11.2** Pond nutrient flows in an integrated aquaculture, crop, and livestock system (IAA-farming) in the Mekong Delta of Vietnam (Nhan et al. [6], with permission of Elsevier)

## 11.7 Selecting Plant Species

Phytoremediation options designed to control and treat the identified contaminants in aquaculture systems will also be very site specific and must be carefully planned to accommodate the individual characteristics of a particular aquatic system. Design parameters must allow for the integration of phytoremediation processes with the basic operational schemes of common aquaculture systems. Native plants with a relatively rapid growth rate and high biomass production are the most effective

**Table 11.1** Water quality problems and selected contaminants in aquaculture systems

| Water quality problem | Selected contaminants |
|---|---|
| Suspended and dissolved substances | Inorganic and organic materials—TSS, TDS |
| Nutrient loadings | Nitrates, nitrites, phosphorus, unionized ammonia |
| Oxygen depletion—Biochemical Oxygen Demand (BOD) | Dissolved organics, sediment oxygen demand |
| Increased phytoplankton and toxic blooms | Oxygen depletion, organic contaminants, microbial toxins |
| Increased inorganic contaminants | As, Al, Cd, Cu, Pb, Zn) |
| Increased organic contaminants | Malachite green, pesticides, algicides, herbicides, petroleum hydrocarbons |
| Microbial pathogens and parasites | Bacteria, viruses, protozoa, trematodes, cestodes, nematodes |

candidates for the phytoextraction and phytostabilization of specific contaminants common in aquaculture operations. Basic knowledge about plants and water quality characteristics may be available from farmers and other local residents involved in IAA activities.

Care must be taken to avoid competition between the plant and microbe communities used to treat/remove contaminants and the processes required for cost-efficient aquaculture operations. For example, livestock and crop wastes are typically directed to aquaculture systems to fertilize the biological community that provides food for fish, snails, and other aquatic herbivores under culture (see Figs. 11.1 and 11.2). The integrated aquaculture–phytoremediation design must provide a good balance that insures both the removal of excess nutrients and an adequate supply of nutrients to support the growth of the aquaculture products. Major considerations for an integrated and sustainable phytoremediation–aquaculture system include the specific locale of the facility pond or river, climate/local weather patterns, hydrology, general land use patterns in the surrounding area, and the sources and types of major biological and chemical contaminants entering the water and sediments.

Phytoremediation research in Southeast Asia has expanded considerably during the past 15 years beginning with the initial research completed at Mahidol University and later at Burapha University in Bangkok and Bangsaen Thailand. There is a good database of plant species available in the published literature describing plants used for various applications of phytoremediation in developing countries (see for example [31]).The database can be one good source of appropriate plant species for use in designing integrated aquaculture–phytoremediation systems. Several basic factors should be considered in the process of plant selection. For example, plants used in shoreline and inflow/outflow areas should be chosen on the basis of their growth characteristics in different soils and sediments and their compatibility with other plants in the community.

**Table 11.2** Examples of phytoremediation treatment options for aquaculture systems using constructed communities of plants, algae, and bacteria

| Contaminant removal system | Plants |
|---|---|
| Vegetative filter strips (VFS) [32–35] | |
| Pesticides | *Iris versicolor*, *Trypsacumdactyloides*, *Andropogongerardii*, *Salix nigra* |
| Petroleum hydrocarbons (TPH) | *Trifolium* sp., *Festua* sp., *Cynodon* sp. |
| Heavy metals/metalloids | *Vetiveria* sp., *Chrysopogon* sp., *Chromolaena* sp., *Typha* sp., *Leersia* sp., *Tagetes* sp., *Acidosasa* sp. |
| Natural and constructed wetlands [32, 36, 37] | |
| BOD, TSS, nutrients, heavy metals/ metalloids, organics/malachite green, coliform bacteria, parasites | *Carex* sp., *Cyperus* sp., *Typha* sp., *Phragmites* sp., *Juncus* sp., *Rhizophora sp.*, *Panicum* sp., *Leersia* sp. |
| Limnocorrals/cages/net pens/hydroponic rafts [38–44] | |
| BOD, TSS, nutrients, organics/malachite green, metals/metalloid | *Lemna* sp., *Eichornia* sp., *Hydrilla* sp., *Ceratophyllum* sp., *C. indica* |

## 11.8 Design Parameters for Integrated Aquaculture–Phytoremediation Applications

The pond and river areas available for the application of phytoremediation options to control and treat contaminants in aquaculture systems include (1) water supplying the ponds through direct inputs from inflow channels/canals and indirect inputs from non-point source runoff, (2) sediments in the ponds and rivers, (3) bank areas immediately surrounding the ponds and rivers, and (4) water exiting the pond through outflow channels/canals or downstream flow in rivers. Table 11.2 provides selected examples of potential phytoremediation treatment options for aquaculture systems experiencing common contaminants. Food security and water pollution are of increasing concern, especially in developing countries. Biomass removed from the aquaculture pond or river can be composted, used as fuel, or as food for humans and livestock if the concentration of toxic contaminants is low enough.

## 11.9 Vegetative Filter Strips and Natural and Constructed Wetlands

Vegetative filter strips (VFS) can be applied to areas immediately surrounding IAA/VAC pond shoreline areas (see Figs. 11.1 and 11.2) and to the inflow and outflow areas of the facility. The VFS plant community can be constructed using compatible native plants that are known to be effective in the treatment of specific organic and inorganic contaminant mixtures. In many cases, decorative plants including blue flag iris and marigolds (e.g., *Iris* sp., *Tagetes* sp.) with good phytoremediation potential can provide value-added benefits to farmers as products sold to floral dealers.

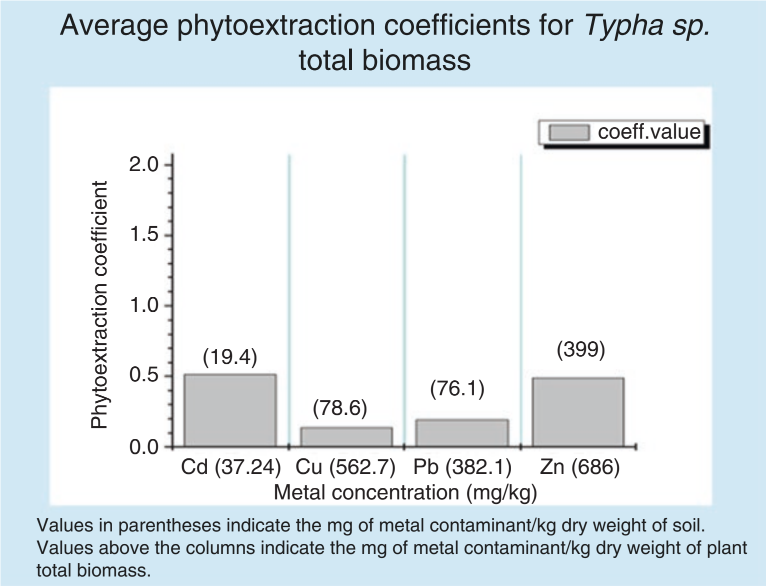



**Fig. 11.3** Average phytoextraction coefficients for *Typha* sp. total biomass

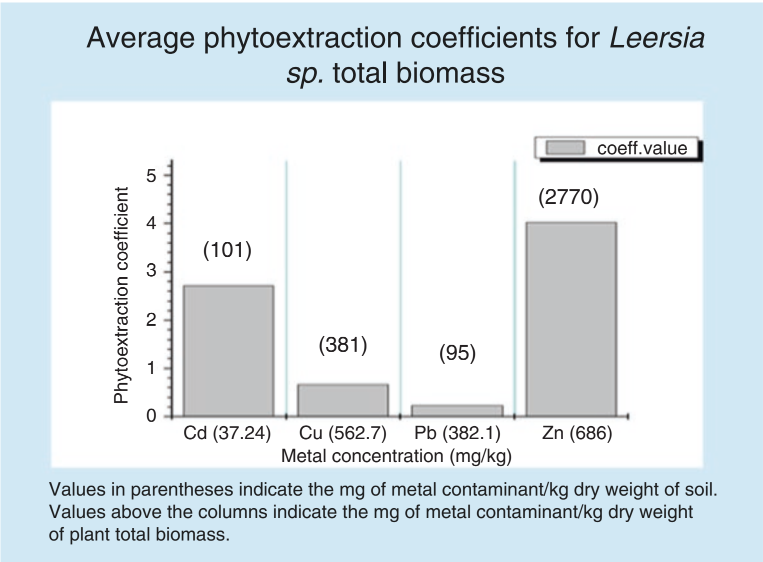



**Fig. 11.4** Average phytoextraction coefficients for *Leersia* sp. total biomass

Natural and constructed wetlands can be used to compliment VFS communities especially at the inflow and outflow areas of an aquaculture pond. Plants used in VFS and/or constructed wetlands should be matched to soil or sediment types similar to their normal habitat. For example, *Typha* sp. grows best in wet, saturated soils

**Table 11.3** Inorganic contaminant uptake by *Leersia oryzoides* in different soils

| Contaminant (mg/kg) | Soil type 1,2,3[a] | Roots | Shoots | SRQ** |
|---|---|---|---|---|
| As | 1 | 30 | 10 | 0.30 |
| AS | 2 | 140 | 140 | 1.00 |
| Cd | 3 | 86 | 16 | 0.18 |
| Cu | 3 | 370 | 11 | 0.30 |
| PB | 3 | 91 | 4 | 0.04 |
| Zn | 3 | 1770 | 1000 | 0.60 |

All soils had percent organic content by weight between 1 and 6. Shoot/Root Quotient Data from Lanza [32], Amphia-Bonney et al. [45]

[a]Soil types 1 = Standard loam, 2 = Potting soil, 3 = Wetland sediments

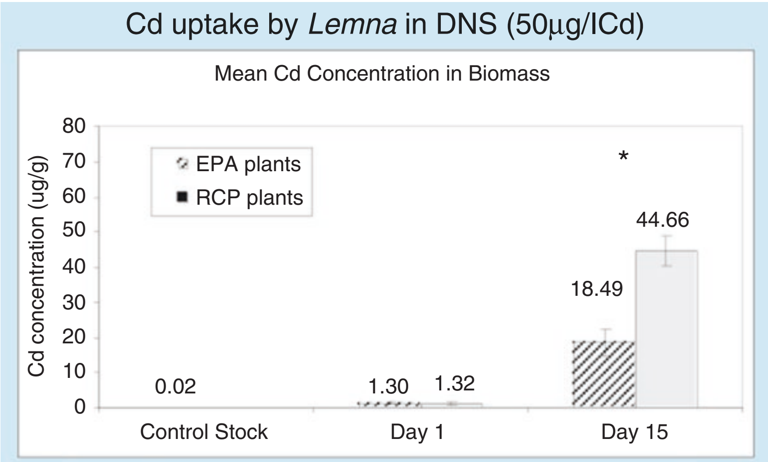
while *Leersia* sp. favors moist to dry soils. Although erratic phytoextraction patterns may occur over time, both plants can effectively remove small to moderate amounts of heavy metals/metalloids, thus preventing the contaminants from entering the aquaculture system and its food web.

Figures 11.3 and 11.4 provide examples of typical phytoextraction coefficients seen with *Typha* sp. and *Leersia* sp. from an industrial area in the USA heavily contaminated with TPH, PCB, and several heavy metals [32]. Table 11.3 displays root and shoot contaminant removal and Shoot/Root Quotients of *Leersia* sp. in test sediments and soils with varying organic content [32, 45]. Total or partial plant removal can eliminate some of the contaminants using successive plantings over time.

## 11.10 Limnocorrals, Cages, Net Pens, and Hydroponic Rafts

Treatment of contaminants in the pond, river basin, or canals can be accomplished with plants housed in containment structures including limnocorrals, cages, net pens, and hydroponic rafts. The site-specific characteristics of the aquaculture operation will determine which type or combination of containment structures is best suited for integration with the aquaculture process. The interaction of different contaminants (e.g., cadmium and zinc) and humic substances are important determinants of contaminant behavior and removal [38] and should be considered in designing a system. The specific absorption/adsorption characteristics of the plant are also important considerations in the planning and design of integrated aquaculture–phytoremediation systems.

In some cases, more than one type of containment structure can be used over time. Caged floating plants could be used simultaneously with hydroponic rafts. Floating Treatment Wetlands (FTW) with *C. indica* [39] could be used along with caged *Eichornia* sp. or *Lemna* sp. Since all aquatic plants absorb contaminants and then release them back to the environment when they die and decompose, the containment structure must be periodically removed, cleaned out, and repacked with




| * RCP Plants | P - Value | Significant Difference |
|---|---|---|
| Day 1 | 0.478 | NO |
| Day 15 | 0.016 | YES |

**Fig. 11.5** Cadmium uptake by *Lemna* sp.

fresh plants. For example, water hyacinth (*Eichornia* sp.) and duckweed (*Lemna* sp.) listed in Table 11.2 absorb nutrients, heavy metals/metalloids, and other contaminants from water. In addition to inhibiting phytoplankton growth by competing for nutrients, the plants remove toxic contaminants such as cadmium. Studies using *Lemna* sp. collected from Rice City Pond (RCP) a cadmium-contaminated pond in the USA (see Fig. 11.5) and an USEPA reference culture of *Lemna sp.* cultivated in synthetic water (DNS) showed very good removal of cadmium after 2 weeks of culture. Using a "put and take" approach with the containment structures will prevent the return of the contaminants to the pond or river by removing biomass before death and decomposition.

## 11.11 Summary and Future Research Needs

Food security and water pollution are of increasing global concern, especially in developing countries. Methods to simultaneously augment food production and decrease water pollution can be valuable additions to current aquaculture operations. IAPS offers a new approach to create sustainable aquaculture systems that can provide green, low energy-low technology solutions in developing countries. If the concentration of toxic contaminants is low enough, biomass removed from aquaculture ponds or rivers can be composted, used as fuel, or as food for humans and livestock. Composting biomass can significantly reduce the volume of plant material, but contaminated biomass would have to be safely disposed of in landfills or other appropriate storage areas [46].

Typical biomass from plant material contains varying amounts of stored energy as oxygenated hydrocarbons biomass. As a result, it can serve as a reliable source of fuel if the amount produced merits collection and storage. The dry weight of *Brassica juncea* used to phytoextract lead from soil produced 6 tons biomass per hectare with 10–15,000 mg/kg lead content [47]. The use of biomass for fuel may be feasible as an augmentation to traditional solid fuels combusted under controlled conditions that do not release contaminants to the atmosphere. In the case of biomass use as food for livestock and humans, studies of nutrient removal by *Lemna* sp. from two ponds in Brazil indicated that the ponds together produced over 13 tons of biomass (68 t/ha year of dry biomass), with 35% crude protein content [36].

Using Integrated Aquaculture–Phytoremediation Systems (IAPS) can greatly enhance the global production of plant and animal food particularly in developing countries with warmer climates and highly diverse plant communities. Although IAPS will remain site specific, additional research can clarify the most efficient plant communities for many common types of aquaculture systems based on general similarities in the aquatic products grown and the waste types and loadings typically used to fertilize the food web supporting production. Information on IAPS that create a balance between the livestock fertilization supporting good aquatic product growth and excess fertilization that leads to undesirable water quality that impedes good aquatic product growth will be very useful.

The presence of various microbial pathogens and parasites present a major challenge to sustainable IAPS and aquaculture systems in general. Additional research is needed to develop IAPS that provide the effective removal of disease causing organisms common in aquatic systems used for aquaculture. One good example is provided by fish-borne zoonotic trematodes (FZT). Current research indicates that fish-borne zoonotic trematodes FZT such as *Clonorchis sinensis*, *Opistorchis viverini* (*Opisthorchiidae*), and intestinal trematodes of the family *Heterophyidae*, constitute a public health hazard in Vietnam. These parasites have been linked to consumption of raw or undercooked fish from aquaculture [11]. The FZT transmission pathways, however, are more complicated than just the presence of intermediate snail hosts in aquaculture ponds as ponds may exchange water with surrounding habitats such as rice fields and irrigation canals (see Fig. 11.1), and these surrounding habitats may be a source of snails and cercariae and contribute to FZT infection in cultured fish [11].

The fact that snails are often harvested as food from aquaculture ponds and rivers complicates the problem of FZT. Research is needed to clarify the possible inclusion of carnivorous plants in phytoremediation communities used in IAPS (see Table 11.2). Plants in the bladderwort group (e.g., *Utricularia* sp.) inhabiting wet soils and water are known to actively trap and consume aquatic animals including mosquito larvae and tadpoles [48]. It may be possible to use bladderworts to remove immature snails, snail eggs, miricidia, and cercariae as a treatment option in IAPS. IAPS may contribute to providing a holistic approach to deal with all stages of the FZT transmission cycle.

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