BioCepts International Inc.

A BRIEF HISTORY OF AQUACULTURE RACEWAY DEVELOPMENT

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By

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EXECUTIVE SUMMARY

Definition - A raceway is a channel or tank with a continuous flow of water constructed or used for high-density fish (marine or aquatic organism) production.
www.nrcs.usda.gov/Internet/FSE.../nrcs143_026152.pdf)

The aquaculture term "raceway" is a highly generic term and implies little more than a water impoundment with water flowing through it. The Romans and perhaps even earlier cultures - used complex water management systems to effectively create and manage both aquaculture raceways and static pond systems. They used both tidal, and or freshwater stream head differences to manage and produce both marine and freshwater species for food. (Costa Pierce, 2005).

It is likely that fish farmers - primarily trout farmers have been using various kinds of raceways for aquaculture in the US since the late 1800s. The Marquette State Fish Hatchery was using raceways in 1926. The Platte River State Fish Hatchery opened its first raceways in 1928.

Figure 1. Marquette State Fish Hatchery raceways 1926).

Like the evolution of one story to two and then multi-storied buildings - the advent of stacked raceways were an inevitability. Tropical fish farmers have been using stacked production raceway and stacked static tank systems since the 1920s. The aquaculture concept of raceways and stacking raceways has been and continues to be used in many commercial aquaculture species production. Stacked tray production systems (raceways) are pretty much a by-product of the industrial revolution's economic optimization processes - realizing that utilizing floor space by stacking trays or tanks could increase the efficiency of capital investments.

The Japanese were experimenting with shrimp production systems since the 1930s - it's quite likely that they to produced shrimp in long tanks with water flowing through them - "raceways" very early. Regarding the production of shrimp in stacked raceways it isn't probable that there were many shrimp stacked raceway experiments in the US before the early 1970's - since shrimp farming didn't start until the late 1950's" and commercial efforts started in the late 60s.

Though there may have been earlier, the earliest use of stacked shrimp "raceways" photographically recorded to date - is in 1972 at Ralston Purina's Mariculture Research Center and numerous other records continue there after. There is no recorded single inventor with which to credit the discovery of the raceway or its evolution to a stacked raceway concept.

The evolution of the linear aquaculture raceway started with at least as far back as the Romans. After reviewing known examples chronologically it is easy to see the evolutionary path of the stacked raceway and its related variations and they are apparent and straightforward. Many of the stacked raceway refinements and variations have come from many aquaculture species and even other non-aquaculture elements of modern industrial agricultural food production and even including sewage processing technology.

Linear to Stacked Raceways

Once the concept of linear aquaculture raceway was created, it languished for millennia. That is until the industrial revolution spurred new interests with regard to higher food production per unit effort advanced further sophistication. With the industrial revolution the raceway concept evolved into increasingly more space/volume efficient and capital resource utilizing variations - achieving smaller ever-smaller footprints for the same, or greater production levels - for a wide variety of aquaculture species from crustaceans, fish and mollusks and others.

The first space decreasing and footprint efficiency-Increasing configuration of the raceway was the rather obvious idea of stacking one raceway on top of another - just like multi-storied buildings. From the initial "stacked" raceway concept - at least three variations descended.

Suspended Shallow Tray Stacked Raceways

Stacked raceways have been conceived in as high a configuration as structural and stabilizing construction material integrity would allow. Stacked raceways must be built of strong, lightweight, waterproof and corrosion resistant materials such as wood, fiberglass, plastic, and corrosion proof metal. Structural integrity and the material cost of supporting large volumes of water required for commercial aquaculture production are the primary limiting factors with structurally suspended stacked raceways.

Suspended "V" Type Stacked Raceways

In order to minimize structural supports, designers constructed shallow raceway trays (usually for shrimp, mollusks and flat fish) to keep the tray volumes and liquid weights to a minimum. In other designs - particularly for fish, deeper and narrower channels were conceived where the weight of the higher volumes were countered with narrow span widths of the inherently strong "V" configurations (see channel catfish raceways - Fig. 12.).

Submerged Raceways

The next major evolutionary design configuration of stacked raceways were designed to reduce the amount of weight supporting structural materials for each layer. To accomplish this the "raceway" layers were produced in light wt. trays - either solid or screened and the trays then submerged in a master raceway tank containment where water could be flowed collectively or independently through each submerged stacked "raceway" trays and either flowed horizontally or vertically (up-wellers and down-wellers). This submerged layered raceway system has been primarily used in the culture of crustaceans (shrimp, crayfish, and lobster) and mollusks (oysters, clams, conchs, and others).

Non-linear Raceway Concept Variations

If we accept that the definition of a raceway is a channel or a tank in which water flows to cultivate marine and aquatic organisms - then we must also accept that those water flows don't necessarily have to be in a completely straight and linear fashion - as the earliest channel type raceways were designed and as particularly trout raceways still are. In fact, a little basic study of hydrodynamics shows us that contained water doesn't particularly like to flow in straight lines. Frictional forces of sidewalls, and or obstacles - inevitably create eddies and or vortexes that redirect otherwise linear flow lines.

No one knows whether it was a bowl of soup, a vat of wine, or a cup of tea wherein the solids and or dregs were first observed moving to the center of the circular containment. Clearly this observation inspired the concept that solids tend to move to the center of the "swirl" - where the velocity of the water column in question was at it's lowest. It was undoubtedly an observation such as this that gave creation to the "circular" raceway. Cornelius Mock of the Galveston Marine Laboratory was one of the first to use and adapt a number of non-linear raceways in intensive shrimp production systems. He said he observed this techniques being used in waste treatment settling tanks.

Circular raceways - They are usually round tanks (or polygonal tanks with "rounded" corners as per the Taiwanese shrimp industry of the 1980s) of medium depth (up to a meter and a half) and whose diameter is a function of the velocity of the water flow. The water flow velocity is then a compromise between the flow tolerances of the aquaculture species used and the hydrodynamic characteristics of their waste. In general velocities need to be higher to transport heavier wastes, which settle in the center of circular tanks allowing them to be conveniently be removed by drains or manually.

Circular raceway advantages are that their construction requires the least amount of containment materials per unit volume contained - all forces directed radially and equally against the sidewalls. This is unlike rectangular systems that require much more structural to maintain the rectangular shape.

Their biggest disadvantage of the circular raceway is that they have a limited diameter, before the velocities at the center of the circular flow system become a "dead" area where circulation cannot reach and or transport the solids effectively to a pickup point. This effect can be used to an advantage to settle wastes, but within very finite limits - in most aquaculture circular raceways are limited to less than 90 meter diameters. Another disadvantage of circular raceways with regard to spatial efficiency is that they tend to waste between 10-20% of the typical rectangular property footprint compared to rectangular systems. However, in most overall cost analysis of circular raceways, they have been found to be less expensive on an operating basis than rectangular systems. This primarily due to higher energy in puts in rectangular necessary to maintain comparative water quality levels.

Oval raceways - The "oval" raceway is essentially a circular raceway - with two halves of the circular tank extended so that there are two channels with a half circular raceway at each end. In other words, a circular raceway that has been stretched into an elongated system - a long rectangle with round ends. Oval raceways generally have a center wall dividing the tank and the opposing flows from the radius of one round end to the radius of the other round end to separate and maintain the respective flows of each side in opposite directions. The advantage of the oval raceway is that it is more spatially efficient than the circular raceway and consequently can contain both larger volumes per unit. The oval raceway (like its derivative circular raceway) has

the ability to collect solid wastes, but in the oval raceway case - wastes collect on the downstream side of each end radius.

Elliptical and donut raceways - It is also possible to move water in other planes than the horizontal and still meet the generic definition of a "raceway". There are aquaculture production systems where the flows within a rectangular/"U" profiled tank - sometimes called an "elliptical tank" are directed in a "rolling" spiral pattern down the length of this elliptical raceway. As well, there are circular tanks where the flows are not concentric, but are actually created in circular spiral - for lack of a better name - a "donut raceway". These tanks are essentially the same as an elliptical tank in a circular configuration. Both the elliptical and the donate raceways have primarily been employed as larval rearing hatchery tanks.

All of the above non-linear raceway configurations have also been produced in various stacked raceway designs. Some of the designs obviously lend themselves more to stacking, either suspended, or in submerged from. The following section will photographically demonstrate the evolution of stacked raceways in aquaculture species and with shrimp stacked raceway concepts as well.

1972 - Ralston Purina Mariculture Research Center, Crystal River, FL. A stacked shrimp "raceway" flow through experimental production system. (Photos Durwood M. Dugger collection.)

Figure 2. Ralston Purina Stacked "Raceway" system (1972).

1973 - Ralston Purina Mariculture Research Center, Crystal River, FL. - Stacked experimental "raceway" flow through experimental production system. (Photos Durwood M. Dugger collection.)

Figure 3. Ralston Purina Stacked "Raceway" system 1973)

1973-1974 - Ralston Purina Mariculture Research Center, Crystal River, FL Stacked raceway proto-type system. (Photos Durwood M. Dugger collection.)

Figure 4. Under construction, 1974 Stacked raceway in operation (1973).

1973 - Syntex Pharmaceuticals Inc. - Palo Alto, Ca. developed stacked raceways culture in their efforts to produce freshwater shrimp commercially. (Private correspondence - Phil Boeing, 12/19/11.)

1974 - Ralston Purina Mariculture Research Center, Crystal River, FL. Another stacked "raceway" system which Purina developed using screened trays 4-5 cm apart in one single volume about 8 feet deep. Photos below show the show the sidewall of this prototype system (note the massive 6"x8" timbers used to contain the water pressure.), and the top views showing the four - 4'x4'x8' raceway stacks and their individual feeding tubes - in an 8'x8'x8' pilot system. This system produced the highest volumes per unit area (foot print) and volume of any of the shrimp raceways documented to date. (Photos Durwood M. Dugger collection.)

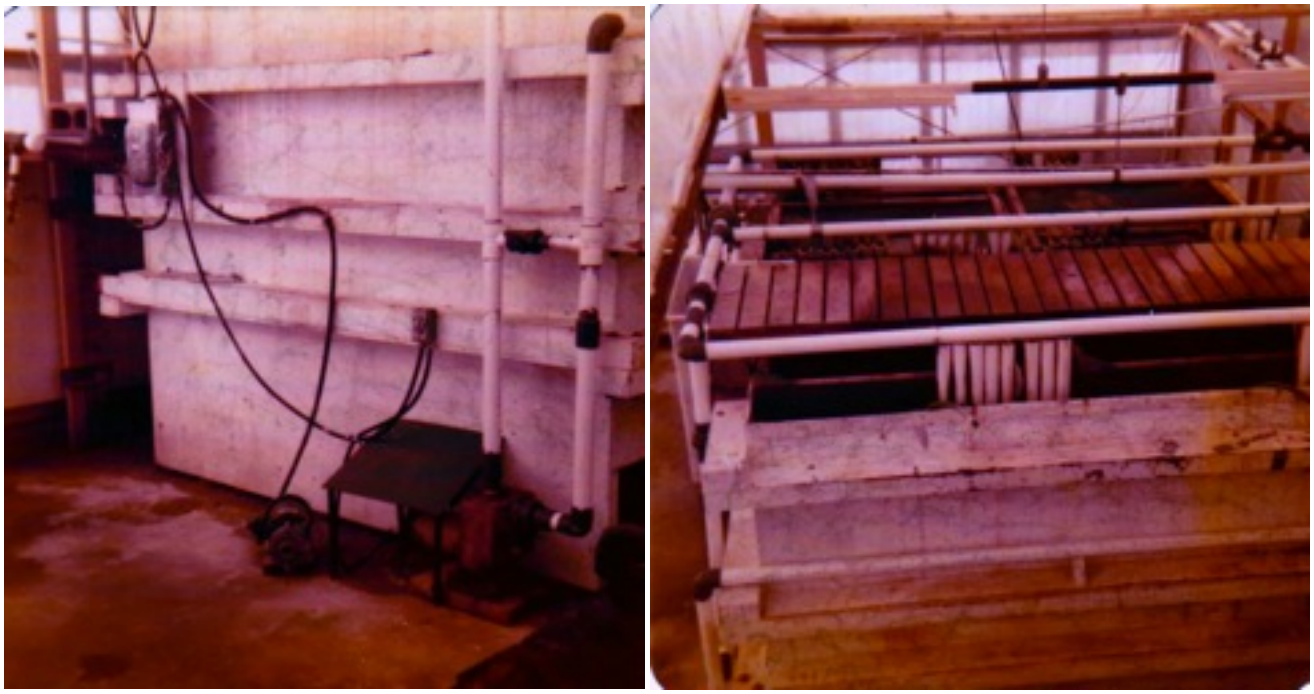

Figure 5. Ralston Purina stacked "raceways" in single volume condo system (1974).

1975 - Aquaprawns/Sun Oil Co., Port Isabel, Texas - Stacked (2 high x-3 sets) shrimp recirculating shrimp nursery and broodstock systems. (Photos Durwood M. Dugger collection.)

Figure 6. Aquaprawns/Sun Oil Co. Stacked shrimp broodstock/nursery circular, recirculating "raceways" (1975).

1979 - CSCI, Inc./AMFAC, Inc. Port Isabel, Texas - Another "stacked" raceway using a netting system in a single volume. It was developed under contract for AMFAC. Hurricane Allen in conjunction with an AMFAC reorganization ended this intensive shrimp pilot circular raceway system development. (Photos Durwood M. Dugger collection.)

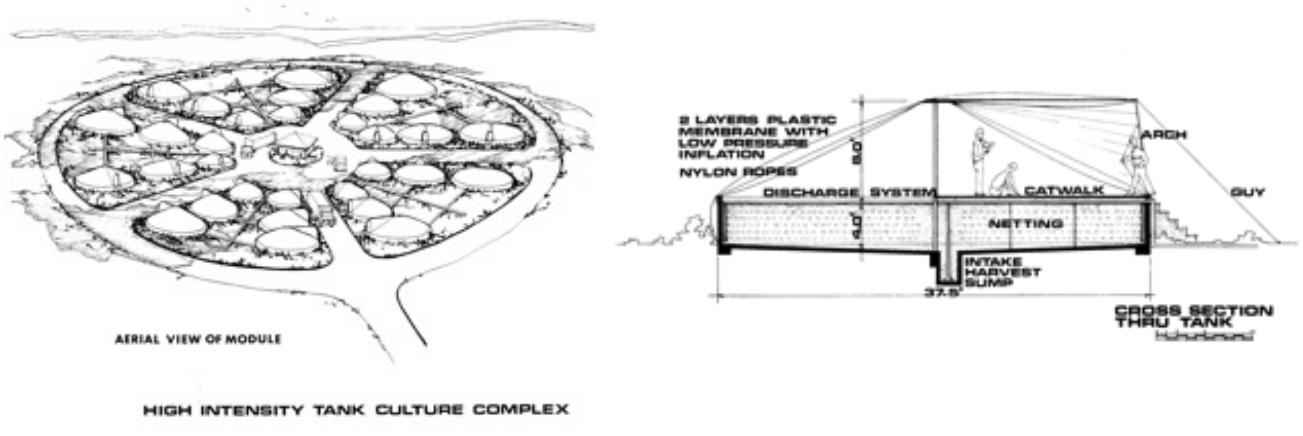

Figure 7. CSCI, Inc./AMFAC, Inc., Stacked "net trays" within circular "raceway." (1979)

1980 - King James Shrimp Farms, Inc., Chicago, Ill. - Used stacked raceways housed in an old retired brewery. I have tried to contact some of their employees of the time, but did not get a response to my emails for a request of photos of their system. However, the system is referenced in the following book on shrimp culture. Pure public record from an independent source!

A 'battery' operation, King James Shrimp Ltd of Illinois, USA, produced shrimp in indoor stacked raceways within a heated 'closed' recirculating system, but went bankrupt in 1982. The system employed artificial seawater, of which 10–15% was exchanged each day. Yields of 1–1.5 kg m^{-2} were obtained (McCoy 1986). Another

(Wickens, 2002)

1994 - Aquatic Design, Ltd., Russ Allen, Lansing, MI - Also, a shrimp stacked raceway developer and one which I'm pretty sure is system referenced below. I requested photos by email - he responded - and I paraphrase as follows: "I've been working with stacked raceways since 1994. I have lots of photos, but I cannot openly share them. I would need to know how the photos would be used and need non-disclosure agreements with all parties involved."

of 1–1.5 kg m^{-2} were obtained (McCoy 1986). Another super-intensive system with stacked raceways, nine units high, has been set up more recently in Michigan (Rosenberry 2000b). Raceways are made of reinforced concrete, are compartmentalised for two-phase ongrowing and are sloped for self-cleaning. Water cascades between levels to aid oxygenation and the whole system is operated in the dark.

(Wickens, 2002)

1998 - BCI, Inc./Zeigler Brothers Feed Co. - Durwood Dugger developed stacked shallow tray raceway tanks used for nutrition experiments. (Photo - Durwood M. Dugger collection.)

Figure 8. BCI, Inc./Zeigler Brothers Feed Co. - Experimental stacked shallow tray "raceways" (1998).

1998 - Bonnie, Hopkins and Laramore, Inc./HBOI - Fort Pierce, FL - Dr. Rolland Laramore developed a series of stacked recirculating shrimp raceways nursery tank systems. The tanks used were the same kind of fiberglass shallow trays in the above picture, but were located within a wooden support framework.

2005 - Llyn Aquaculture, Ltd. - "The project was conceived as a preliminary trial to grow *Penaeus vannamei*, the tropical pacific white legged prawn which is traditionally grown in extensive outdoor ponds in the tropics. If a system and techniques can be developed to grow premium quality at our site in N. Wales then these will be in great demand by top end restaurants and consumers specifying a fresh (same day as harvest), sustainably grown (zero water exchange & emissions) and low food miles traceable product.

At Llyn Aquaculture, Ltd **we adapted a series of shallow raceway tanks** previously used to great effect with flatfish, **for shrimp**. In part, the pilot was intended to test to what density the shrimps could be grown to in these tanks, and also to test the practicalities of adding a plastic biomedia structure to the tanks primarily as shelter for the prawns to minimize cannibalism and aggression." (*www.seafish.org/media/.../10508_shrimpshallowracewaytrial.pdf)*

Figure 9. Llyn Aqua, Ltd. - Adapted shallow stacked flatfish raceways for shrimp production (2005).

The evolution of stacked raceways has not been dependent on shrimp aquaculture. Stacked raceway design variations for other aquaculture species have continued in parallel with stacked shrimp raceway evolution, and or versa. In addition there are countless applications of stacked growout systems generically and endemic in the food and ornamental production growing systems that transfer at least in part to aquaculture. For example stacked trays tanks used in agriculture from germinating bean sprouts. Stacked trays for growing mushrooms (where my original stacked raceway concept came from - Purina had a stacked, computer operated mushroom farm in Zellwood, FL in 1972.). Some of the first Purina stacked raceway designs relied on Purina's experience in the movement and collection of solid wastes from their poultry production businesses. Not only do these non-aquaculture stacked tray growing systems have influence on aquaculture stacked raceway designs, but the associated service systems (feeding, harvesting, heating/cooling, product moving, and computer instrumentation) are often similar or the same.

This section shows some of the non-shrimp stacked raceway system development - in other aquaculture species that were ongoing with the development of stacked raceways in shrimp production.

1976 - System Culture Corporation, Hawaii - Tap Pryor. Developed as system of stacked trays for oysters in raceways. (Photos - Durwood M. Dugger collection.)

Figure 10. System Culture Corporation, Hawaii - Stacked plastic oyster trays within concrete raceways (1976).

1980 - Patent for stacked tray "raceway" system for hatching fish eggs - (http://www.docstoc.com/docs/31181332/Fish-Egg-Supporting-System---Patent-4214551

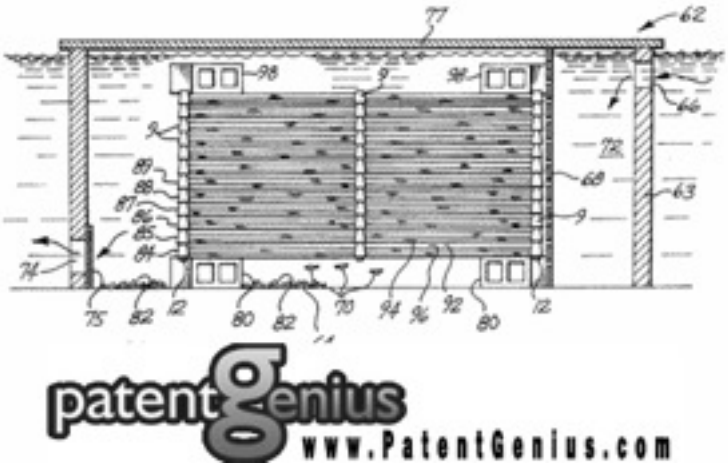

Figure 11. Patent-4214551 - Stacked tray raceway for hatching fish eggs (1980).

1983 - University of MN. Stacked catfish production raceways. "Growth varied significantly ($P < 0.001$) among fish from the three passes **of the stacked raceways**, declining from a mean specific growth rate of 1.28 %/day in the first pass to 1.17 %/day in the second pass and 1.13 %/ day in the third pass (Table 3). " (*conservancy.umn.edu/bitstream/112661/1/MiscP28.pdf)*

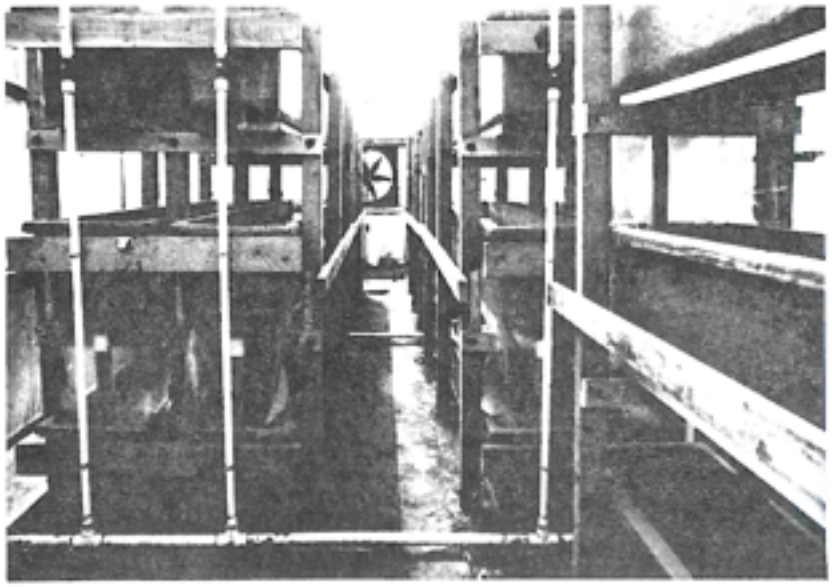

Figure 12. University of Minnesota - Stacked fiberglass raceways for catfish production (1983).

1996 - Harbor Branch Oceanographic Institution, Fort Pierce, FL - Floating raceways (up-wellers and down-wellers) with stacked plastic trays for oysters and clams and suspended stack tray raceway systems used in commercial mollusk culture all over the world.

Figure 13. Commercial shellfish stacked Nestier trays - in floating raceways or suspended (1996).

2002 - Llyn Aquaculture, Ltd. - "At the Llyn Aqua pilot plant in N Wales we have held a breeding stock of selected fish since 2002 and rear about 5 tonnes per annum as a test species to further develop our closed systems. Fish of up to 100g are kept in stacked shallow raceway nursery systems (< 10 cm depth) and thrive at up to 25 Kg / m2 and larger fish show optimum growth in shallow (0.3 - 0.7m) round or raceway tanks at densities up to 40 Kg / m2." (http://www.llyn-aquaculture.co.uk/index.php?p=114)

Figure 14. Llyn Aquaculture - Stacked flatfish raceway (2002).

2007 - Juvenile spotted wolffish production. "The technology is especially well suited for land-based production of flatfish like turbot, *Scophthalmus maximus* (Rafinesque); and halibut, *Hippoglossus hippoglossus* (L.); or bottom-dwelling species like the spotted wolffish, *Anarhichas minor* (Olafsen), as it opens possibilities for reduced land requirement and building investments as well as reduced water consumption, by **stacking the raceways** in several levels and reusing the water from level to level.
(*www.sjavarutvegur.is/fisk/pdf/.../JWAS%2038,%20154-160.pdf)*

2008 - **Lab-Scale Zero Exchange Shrimp Aquaculture -**
The designs ranged from methods **that stacked platforms to maximize the amount of shrimp that can be cultivated in a tank..**. These concepts all featured an internal biofilter and in the donut design, the ability to be stacked." (Student project. No photos available.).

2008 - Orlando, FL WAS Trade Show Exhibits - Mini-stacked "raceways" systems for shrimp and fish experimentation. Aquatic Habitats, Inc. (http://www.aquatichabitats.com/)


Figure 15. Aquatic Habitats, Inc. Mini-stacked recirculating raceways for research experiments (2008).

2009 - Hubbs-SeaWorld Research Institute, San Diego, CA. (HSWRI) - Integrated Larval-Nursery System For California Halibut - "The pelagic larvae were then transferred to the raceway RAS by transfer pipes that exited the cone tanks at an elevation corresponding to one of t**he three vertically stacked raceways. (***pdf.gaalliance.org/pdf/GAA-Stuart-May09.pdf)*

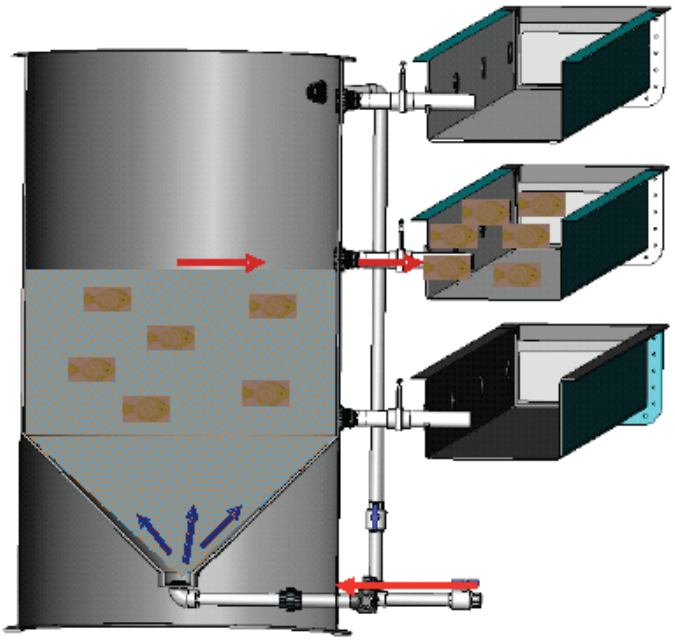

Figure 16. Hubbs-SeaWorld, San Diego, CA. - Integrated Larval-Nursery System For Ca. Halibut (2009).

It should be quite clear to anyone who adequately reviews the history of aquaculture raceway development and its evolution into the many varied forms of raceways - including stacked raceways, that the process has continued over many decades with contributions published and documented from many sources - research institutions, companies, and individuals. As such, the technological residue of all of these individual developmental contributions into stacked raceway devices for at least 40 years - should be more than sufficient to establish the basis of a substantial "prior art claim" against the specifically patenting stacked raceways for the purpose of producing shrimp and many other aquaculture species.

However, it should be further understood that this does not preclude any individual or business entity from patenting a stacked raceway production "system" and or a "method" using purposefully assembled devices, or components to produce a "system" that includes stacked raceways as one of the parts of that system - assuming it is done in a sufficiently precise way to establish an "inventive" claim.

By the same token, if another party changes the elements of the aforementioned patent's precision description - materials, dimensions, configuration, growing methods, etc. - this may provide the basis for an entirely new patented and "different system." If nothing else, this document should provide a review of the many ways to build and design a "stacked raceway" system. In the end, the should be the most economically efficient (lowest operating cost/production unit) aquaculture production system that prevails.

Costa Pierce, Barry A. 2005. *Urban Aquaculture*. Technology and Engineering, 285 pp.

Shigueno, K. 1975. *Shrimp Culture in Japan*. Assoc. Int. Tech. Prom., Tokyo. 153pp.

Stuart, Kevin, Micahel Paquette, and Mark Drawbridge. 2009 Global Aquaculture Advocate, pp 70-71.

Wickens, John F., Daniel O'C. Lee. *Crustacean farming: ranching and culture"* Wiley and Sons, 2002, 485 pp.

Wyban, James A., James N. Sweeney, 1991 *Oceanic Institute Shrimp Manual, Intensive Shrimp Production Technology,* The Oceanic Institute, Makapuu Point, Honolulu, Hawaii