Rhode Island Cooperative Extension White Paper Series: No. 2018-1
Published by Rhode Island Cooperative Extension, November 29, 2018
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3 East Alumni Ave., Kingston, RI 02881
DOI: 10.13140/RG.2.2.11937.04966/1

Freshwater Aquaculture and Its Permitting in Rhode Island: Two Case Studies

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Synopsis: In Rhode Island permits to conduct aquaculture, including freshwater aquaculture, are issued by the Coastal Resources Management Council (CRMC) as the designated lead agency by state law. However, by Rhode Island law, aquaculture is considered a form of agriculture. It is the responsibility and duty of the state aquaculture coordinator in CRMC to receive aquaculture applications and coordinate the review of these applications through the multiple federal, state and local agencies that hold regulatory jurisdiction. Since most freshwater aquaculture is conducted on private lands rather than in public trust waters of the state, there is no leasing review. If the proposed aquaculture activity will be in a Water of the State, as defined by the Regulations for the Rhode Island Pollutant Discharge Elimination System (the RIPDES Regulations), or result in a discharge to a Water of the State, the review of freshwater aquaculture proposals will involve water discharge permitting under the Rhode Island Pollution Discharge Elimination System (RIPDES) program administered by the Department of Environmental Management Office of Water Resources. Another area of concern is with any interstate transport and quarantine of live aquatic organisms falling under the responsibility of the Aquatic Biosecurity Board. Case studies of the operations of two former commercial freshwater aquaculture farms, the American Fish Culture Company and the Carolina Black Bass Hatchery are presented as examples of how similar freshwater fish farm operations would be evaluated under the required RIPDES evaluation criteria. Examples of strategies to reduce fish farm effluents are also presented.

Applying for a Permit to Conduct Freshwater Aquaculture

The procedure for applying for a permit to conduct aquaculture is outlined in the General Laws of Rhode Island (GLRI Section 20-10-5) which designates the Coastal Resources Management Council (CRMC) as the lead agency for coordinating the multi-agency review of aquaculture permit applications. The CRMC has the authority to grant permits for aquaculture, including freshwater aquaculture within the State of Rhode Island [per GLRI 20-10-3]. Unlike marine and estuarine forms of aquaculture that are most frequently conducted in the public trust waters of the state and thus require public review and a leasing of submerged lands to establish an aquaculture farm, freshwater aquaculture is, for the most part, conducted on private property, so permitting is handled differently. The official responsible for administering the legal requirements of GLRI Section 20-10-5 is the Rhode Island State Aquaculture Coordinator at CRMC [per GLRI 36-4-2(21)]. The aquaculture coordinator maintains the CRMC aquaculture website (http://www.crmc.ri.gov/aquaculture.html), from which applicants can download an aquaculture application

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package. Once the application is submitted, it is the responsibility of the aquaculture coordinator to work with the applicant and the multiple agencies required to be part of the application review process and approval.

One of the elements of the aquaculture application that may require a permit to be issued is the Rhode Island Pollution Discharge Elimination System (RIPDES) program administered by the Rhode Island Department of Environmental Management Office of Water Resources (RIDEM-OWR), which permits the discharge of pollutants via point source into Waters of the State [per GLRI 46-12-5(b)]. The regulations for obtaining a RIPDES permit are published by RIDEM and are on-line and available for download (RIDEM-OWR, 1984). At fish production levels required to offset land acquisition and site development costs, most commercially viable freshwater aquaculture farms are likely to be designed so that they are classified as "Concentrated aquatic animal production facilities" under the Section 1.4-A-20 -- RIPDES Definitions, and Section 1.68 -- "Criteria for determining a concentrated aquatic animal production facility." The criteria for designating a concentrated aquatic animal production facility are set forth in Section 1.29 of the RIPDES Regulations document. It is very important to note that, even if a proposed aquaculture farm doesn't meet the standard thresholds for designation as a concentrated aquatic animal production facility requiring a RIPDES permit, any aquaculture farm can be designated a concentrated aquatic animal production facility on a case-by-case basis after a farm site visit, and four key factors are considered in the decision to require a RIPDES permit for the project, including:

1) the location and quality of the receiving waters of the State;
2) the holding, feeding, and production capacities of the facility;
3) the quantity and nature of the pollutants reaching Waters of the State; and
4) other relevant factors, including the legal status of the waters of the farm (privately held or public 'Waters of the State') as defined in RIPDES regulations.

Another key permitting issue for freshwater aquaculture are biosecurity and quarantine issues with the cultured organisms covered under the responsibility of the Biosecurity Board of the CRMC [per GLRI 20-10-1.2]. Aquatic organisms brought into Rhode Island from another state may require Biosecurity Board approval and importation permits from CRMC [per GLRI 20-10-12].

Legal Protections of Freshwater Aquaculturists in Rhode Island

Like all other forms of aquaculture, freshwater aquaculture is also considered to be a form of agriculture by the State of Rhode Island [per GLRI 2-23-4(a)]. So as with all agricultural entrepreneurs, aquaculturists are afforded all the protections of Rhode Island's Right to Farm Act [GLRI Chapter 2-23], along with all the privileges and responsibilities of being a farmer. Privileges afforded to aquaculturists include various tax incentives for tools and equipment of the trade [per GLRI 20-10-3.1 and 44-18-30(32)], recognition that cultured species are the property of the farmer even though they may be a regulated fishery species when in the wild [per GLRI 20-10-13], and a general exemption of privately owned aquaculture livestock from the various laws and regulations designed to protect and conserve the state's wild capture fisheries [per GLRI 20-10-13.1].

Case Studies of Freshwater Aquaculture Farms and RIPDES Permitting

If the discharge of aquaculture effluents to 'Waters of the State' are made via 'point sources' , as defined under Section 1.4 of the RIPDES Regulations, they would be subject to RIPDES permitting We present case studies of two Rhode Island freshwater aquaculture farms one of which required an effluent discharge permit, and another that did not, acting as an illustration to how RIPDES Section 1.68 exception criteria are applied (RIDEM-OWR, 1984).

Case Study #1 -- Carolina Fish Hatchery, Richmond, Rhode Island

The Carolina Fish Hatchery, operated by the DEM Division of Fish and Wildlife, is an interesting case of freshwater aquaculture discharge permitting because its operations began nearly a century before the Federal Clean Water Act, and the operations of the farm over its entire lifetime are well documented in the original company correspondence and business records held by the Rhode Island Historical Society Library in Providence. Included in the records are correspondence, billing and invoices about delivery of fish feeds to the farm and correspondence with the U.S. Environmental Protection Agency and the DEM Office of Water Resources.

The Carolina Fish Hatchery is a prime example of a cold-water (salmonid) fish farm in which fish are fed as part of the production cycle and is regulated by the RIDEM Office of Water Resources by way of RIPDES permitting under Section 1.29 -- Concentrated Aquatic Animal Production Facilities. The Carolina Fish Hatchery was formerly operated commercially as the American Fish Culture Company (AFC) until 1995. At this aquaculture facility, the water effluents from the farm are continuously being discharged into the White Brook, which are Waters of the State of Rhode Island, and there are over 35,000 pounds (15,909 kg) of cold water fish (trout) in production at the farm annually. During the summer months, the amount of pelleted feed supplied to the fish regularly exceeds 5,000 pounds (2,272 kg) on a monthly basis, so the criteria set forth in section 1.68 of the RIPDES regulations are exceeded. The Carolina Fish Hatchery, as AFC, received its discharge permit (RI-0001007) through the United States Environmental Protection Agency on July 29, 1974, and renewed several times, most recently on May 1, 2003.[4] Although permits are issued with a 5 year duration, farms may continue to operate under the expired permit as long as the permittee has submitted a "timely and complete" application. The Carolina Fish Hatchery continues to operate as a state-run facility under its 2003 permit.

Figure 1. *The American Fish Culture Company Lower Works (the former Clearwater Trout Farm of Charles W. Hoxsie) circa 1905 with wooden fish weirs directly in White Brook at the time the farm was under supervision of general manager Fred Dean Hoxsie. Photo from a commercial post card from the era.*

Freshwater fish culture began in Rhode Island on the site of the Carolina Fish Hatchery with the pioneering efforts of John Hoxsie in 1877 and his brother Charles in 1879 to establish farms for brook trout

4 NPDES permit document (RI0001007) and the cover letter from the EPA are in the AFC Business Records (held by the Rhode Island Historical Society (subgroup 17, box 2A, folder 1), dated July 29, 1974. Copies of all subsequent NPDES and RIPDES renewals are on file at the RIDEM Office of Water Resources.

in the White Brook area, north of Carolina village in Richmond at 41.4700N, 71.6695W (Rice, 2010; p.20). These farms were established primarily to produce fingerling fish to sell to the Rhode Island Commissioners of Inland Fisheries (a state agency that was the forerunner to the Department of Environmental Management) for stocking of depleted anadromous fish runs around the state caused by numerous industrial mill dams. These two fish farms played a key role in fisheries conservation efforts at the time (Figure 1). In the earliest years of the 20th century, the two farms were eventually acquired by the Hazard Family of Peace Dale and operated as the American Fish Culture Company (AFC). It was first incorporated in Maine in 1892, then later restructured in 1926 as a Rhode Island corporation. By 1901, AFC eventually had grown and expanded their operations to include the production of adult fish for sale as both canned and fresh fish into regional seafood markets (Rice, 2010; p.23).

In the farm's early years under the leadership of the Hoxsies, and later as AFC, feeds in the form of meat byproducts from a meat packing houses were routinely used. For example, during the fiscal year September 1907 to August 1908, about 60,000 pounds of trout were produced by AFC but the fish were fed about 250,000 pounds of ground hog plucks (lungs, windpipes, and hearts) that were shipped in iced barrels to Carolina from the North Packing and Provisions Company of Boston (Rice, 2010; p 24). It is obvious from the amount of feed required and the amount of fish being produced (and a food conversion ratio of about 4.2), that a considerable amount of waste was being produced, and that waste would be flowing down the White Brook into the Pawcatuck River, and down to Westerly on the coast. By 1921, AFC had become the largest fish farm in America (*Providence Sunday Journal*, 1921). In the late 1920s, trash fish caught primarily by the Galilee fishing fleet replaced the meat packing byproducts and proved to be a superior feed for trout, but the food conversion ratios were still high (estimated to be 3.5 to 4), creating considerable water pollution downstream. An important note on these early feeding efforts is that, since they were used prior to the passage of the Clean Water Act and Rhode Island's subsequent adoption of the RIPDES Regulations, a RIPDES permit was not required at the time. However, due to concerns over water quality impacts, this method of fish feed (i.e. feeding of excessive quantities of slaughterhouse or meat packing wastes, or the feeding of excessive quantities of raw trash fish to farmed fish) ***would not*** be authorized under the current RIPDES program.

As fish feed technology improved over the mid-20th century, AFC kept on the leading edge of the technology which greatly decreased farm effluent pollution. Pelleted fish feeds were introduced in 1953 (Brockway, 1953), and AFC was an early adopter of the technology by 1955 which had greatly reduced reliance on perishable meat packing byproducts or trash fish, reduced farm labor costs, reduced feed storage costs, including electrical consumption, and of course, reduced the amount of waste effluents flowing down the Pawcatuck River toward Westerly (Figure 2; *Providence Evening Bulletin*, 1955). At this time, the farm was producing in excess of 75,000 pounds of trout annually (with feed conversion ratios less than 2), but these were still the days prior to the 1972 Federal Clean Water Act mandating controls of water pollution.

By the time the U.S. Federal Clean Water Act was passed in 1972, and regulations were developed for National Pollution Discharge Elimination System (NPDES) permits in 1974, there were 39,000 pounds of trout being produced in the Carolina facility.[5] A federal NPDES discharge permit was therefore required, with the first such permit (RI-0001007) being issued in 1974. The NPDES permit was renewed six years later on June 12, 1980. In 1984, Rhode Island became a 'delegated state' by the USEPA with regard to NPDES permitting, so the RIDEM Office of Water Resources began administering the state RIPDES program, which includes regulation of aquaculture effluent discharges. The first RIPDES permit for AFC (RI-0001007) was issued on December 31, 1986 by the Office of Water Resources. Although AFC facilities were begun to be sold to the state in 1995, with the last of the land transfers occurring in 1997, the

5 From the mid-1950s to the 1970s AFC was faced with mounting business competition from larger scale trout producers in the West and the establishment of large scale state fish hatcheries in Connecticut and other New England states that cut into AFC revenue, forcing major cutbacks in fish production (see review by Rice, 2010).

former AFC fish farm is still in operation today as the Carolina Fish Hatchery operated by the RIDEM Division of Fish and Wildlife as a public fish hatchery (Rice, 2010; p. 29). All RIPDES permitting has continued forward uninterrupted in its renewals through the Office of Water Resources, however trout production at AFC has continued on using the same methods used since the mid-1950s.

The RIDEM Office of Water Resources has received numerous complaints about excessive aquatic vegetation downstream of the Carolina hatchery that are likely the result of phosphorus discharged from the hatchery. Efforts have been underway to work with the Division of Fish and Wildlife to reduce phosphorous effluents at the hatchery by requiring the use of specially formulated feeds that have reduced phosphorous content. This change in fish diets has reduced some of the phosphorous loading but it has not completely solved the problem of excessive aquatic vegetation downstream.

Figure 2. *American Fish Culture Company raceways and hatch house in the Lower Works area. Photo in a 26 October 1955 article in the* Providence Evening Bulletin. *Photo from* Providence Journal *archives.*

Since 2010, the RIPDES program has begun including total phosphorus (TP) limits in the permits it has issued to other trout hatcheries. For example, Rhode Island's largest and most intensive trout production facility in terms of pounds of fish produced is the Lafayette Fish Hatchery in North Kingstown (41.5664N, 71.5065W). The Lafayette Hatchery has a long history as a state fish hatchery but it was refurbished in 2002 to include a number of upgrades, including greater control of effluent water quality including total phosphorus (TP) reduction. The Lafayette Hatchery RIPDES permit (RI0110035) issued on September 29, 2010 contains TP limits of 25 µg/L. This limit was assigned to be protective of water quality in the downstream Bellville Pond and to be consistent with the Total Maximum Daily Load (TMDL) report requirements for Bellville Pond. Subsequent to issuance of the Lafayette hatchery's 2010 permit, the RIPDES Program entered into an agreement with the hatchery whereby it is evaluating various compliance alternatives to meet the TP limit. When the Carolina Hatchery's RIPDES permit is reissued, it will include a TP limit and it is anticipated that the technology identified for Lafayette could also be used at Carolina. Any new commercial fish farm or hatchery discharges to freshwater would also include appropriate TP limits in the RIPDES permits.

Case Study #2 -- Carolina Black Bass Hatchery, Carolina, Rhode Island

Another successful Rhode Island freshwater fish farm with a long history was the Carolina Black Bass Hatchery established in April 1935 by Roland E. Eddy and William F. Tanner immediately downstream from the American Fish Culture Company, also drawing and discharging water into the White Brook (Figure 3) and located near the confluence with the Pawcatuck River at 41.4625N, 71.6724W. The

Carolina Bass Hatchery operated as a privately held fish farm until November 2001, when its lands were sold to the State of Rhode Island by Roland Eddy's son and heir Walter to be managed as as open space area (Rice, 2010; p. 25).

The nine ponds of the Carolina Black Bass hatchery were about 0.33 acre (0.13 ha) each with a 0.5 acre reservoir pond to assure that the production ponds could be topped off during drought periods (Figure 3). The ponds were managed using extensive aquaculture management protocols that relied upon low fish stocking densities, stocking multiple species of warm water fish feeding on different sources of prey along the food chain (microalgae, zooplankton or forage fish), and use of fertilization to stimulate microalgae, and thus the entire food chain. Effort was made in the early spring to stock broodstock fish of various local Rhode Island species, including black (or largemouth bass, *Micropterus salmoides*) as the primary target species for sale for stocking recreational fishponds, and yellow perch (*Perca flavescens*), sunfish (*Lepomis gibbosus*), and golden shiners (*Notemigonius chrysoleucas*) and other small cyprinid fish to serve as forage species for the bass (Eddy, 2018). Fish were stocked at a ratio of 1:10 bass to forage fish with about 2000 bass fingerlings (2- to 4-inch each) stocked per pond. Pond preparation prior to stocking consisted of adding a combination of sheep manures obtained from local farms and superphosphate fertilizer (calcium biphosphate) to the pond waters prior to stocking. The fertilization would promote blooms of microalgae and zooplankton such as *Daphnia*, to serve as food for the forage fish. The amount of fertilizer to be used was determined practically by observing the amount of excess floating algae in the ponds that indicated over-fertilization and potential for overnight hypoxia. This was critical because no supplemental aeration was used in the ponds. In general, about 600 pounds of sheep manure per acre (~700 kg/ha) were used for

Figure 3. *The Carolina Black Bass Hatchery was begun in April 1935 by William F. Tanner and Roland E. Eddy, the manager of AFC. This farm was located immediately downstream of the AFC Lower Works on the White Brook in Carolina. The farm was operated by Roland's son Walter E. Eddy until 2001, when the land was sold to the State of Rhode Island. The water supply impoundment pond is the oval-shaped pond behind the dam on the left side of the image. Aerial photo by Prof. Wayne K. Durfee of the University of Rhode Island, circa 1972.*

pond preparation in the spring, and that initial fertilization was supplemented with a monthly fertilization with superphosphate over the late spring, summer and early fall month (about five times per growing season) at a rate of about 6 pounds per acre (~7 kg/ha) to maintain the phytoplankton blooms in the ponds.

During the summer months, fish would breed in the ponds, and some of the Carolina ponds could be over-wintered for harvest in the following year. The black bass were harvested from the ponds during the fall when they reached about 4 to 6 inches (10 to 15 cm) in length for sale to sportfishing enthusiasts for fish-out pond stocking. Harvest of the fish from the production ponds consisted of lowering the water level of the pond slowly over a week before harvest until the water level reached about one-third of its original depth. Then on harvest day, a bag-type net would be placed on the pond's water outlet pipe in the drain canal and the gates opened to rapidly drain the remaining water in the ponds. The live fish would be quickly collected, placed in large galvanized milk cans and trucked out to clients for stocking. Clients of the Carolina Black Bass Hatchery were in all the New England states and in eastern Upstate New York (Eddy, 2018).

The legal status of the waters held within aquaculture ponds has a considerable bearing on how RIPDES regulations are applied. It is important to note that the RIPDES Program was not aware of the operation of the Carolina Black Bass Hatchery and, therefore, never evaluated the hatchery for its need for a RIPDES permit. However, according to State Regulations, application of manures in this fashion to the Waters of the State as defined in the regulations ***would not*** be permitted because of unacceptably high fecal coliform bacteria and nutrient concentrations. Fertilization of private farm ponds that were constructed and operated with the sole purpose of being a fish farm or hatchery pond, that do not have any connection to Waters of the State, may be allowed if it was determined by DEM that water in that pond was indeed privately owned water and did not meet the definition of "Waters of the State." DEM ***must*** be consulted prior to construction of any such aquaculture ponds in Rhode Island so that there can be a determination whether the water in the aquaculture ponds is considered to be Water of the State.

In a series of study of 25 privately-owned catfish ponds in Alabama, Schwartz and Boyd (1994a) found that under typical pond management protocols, pond water while being retained remained in compliance with NPDES water quality through most of the year, with greatest potential for pollution of receiving waters occurring during the last stages of harvesting when sediments are stirred up as part of harvesting. In the case of the Carolina Black Bass Hatchery, waters from the nine levee ponds constructed on entirely private land were discharged once a year during the fall harvest season into the Pawcatuck River, which is considered to be Water of the State. For this reason, the fish farm management procedures and the microbiological chemical properties of the waters proposed to be discharged from the ponds like this would have to be evaluated under the RIPDES program before the discharge would be allowed. In the previously mentioned management procedure of using sheep manure as a fertilizer in these private waters, there would be considerable concern about residual fecal coliform bacteria and nutrient levels from the manure application entering the Waters of the State. So in this case, RIPDES review would focus on the dynamics and die-off of the fecal coliform populations in the ponds after fertilization, and any permit would require assurances that the periodic discharges occur only when coliforms and nutrients had reached an acceptably low level in the pond.

Considerable information is available about the rates of coliform die-off or inactivation in freshwater ponds under various conditions. According to a review of 450 data sets in 70 reports, it was shown that water temperature affects the rate of die off of or inactivation of coliforms in fresh waters, and hundred thousand to million-fold (5 to 6 log) reductions in coliform can achieved in 10 to 40 days after cessation of coliform introductions (e.g. manure applications) depending on the environmental conditions (Blaustein et al., 2012). A complicating factor about coliforms in freshwater ponds is that bottom sediments, depending upon their nature, may act as a reservoir for coliforms, thus increasing their survival rates (Pachepsky and Shelton, 2011). And it is known that at the last stages of fish harvesting, the sediments are most severely disturbed, posing a time of greatest risk of discharge of total settleable solids (TSS) as well as the resuspended coliforms (Schwartz and Boyd, 1994b). For these reasons, each individual farm pond and the proposed management protocols, including feeding methods/rates, the timing of harvest and water discharges, would have to be evaluated by DEM before a RIPDES permit could be issued.

Recommended procedures for reducing TSS and other pollutant discharges include harvesting ponds as quickly as possible, and either to not discharge water during the seining phase or to discharge highly contaminated water into a settling basin or retention pond prior to its release into the Waters of the State. It may also be feasible to allow effluents to flow untreated into the environment during the initial drain down prior to seining, because concentrations of potential pollutants are low then.

Many of the issues surrounding the use of organic fertilization of aquaculture ponds could be avoided by designing pond management protocols so that they avoid the drawbacks of fertilization with manures all together. Fertilization with inorganic nitrogen and phosphorous sources would avoid the problem of coliforms entirely, and these inorganic fertilizers have also been shown to adequately promote aquatic food chains for warmwater fish. However, if the management strategy of any pond fertilization is used to promote aquatic food chains as forage feeds, the amounts and schedule for fertilization of the ponds must be evaluated as part of a RIPDES Permit to assure that excessive nutrients are not released into the Waters of the State upon discharge. In the end, simply skipping fertilization of aquaculture ponds all together in favor of simply feeding the fish prepared commercial diets may be an excellent way to assure good quality of periodic effluent water discharges from warm water ponds.

An example of a warm water fish farm that does ***not*** rely upon pond fertilization is the Arcadia Fish Hatchery operated by Rhode Island DEM Division of Fish and Wildlife in Richmond, Rhode Island (41.5570N, 71.6952 W). This hatchery is similar in size to the old Carolina Black Bass hatchery and is set up to produce many of the same warm water fish species for stocking and enhancing sportfisheries in the Waters of the State. However, unlike the old Carolina Black Bass Hatchery, the Arcadia Hatchery has undergone formal evaluation of its facilities and procedures by the DEM Office of Water Resources, and it was determined to be exempted from RIPDES program requirements based on the quantities of fish produced and amount of feed used.

Concluding Recommendations

The comparison between the production methods and business models of the American Fish Culture/RIDEM and the Carolina Black Bass Hatchery are illustrative of how commercial freshwater aquaculture operations operated in Rhode Island in the past and how the current RIPDES regulations would apply to the farms. Both of these two once successful fish farms did not survive for very long into the 21st Century as commercially viable privately-owned businesses, because of their relatively extensive production methods on relatively large land areas. Since farm land is relatively expensive in Rhode Island in comparison to most other states, it is likely that higher intensity aquaculture systems with higher fish stocking densities will be the most economically viable option locally. However, with intensification of aquaculture systems comes higher stocking densities, higher reliance on feeds, and therefore more attention required in developing an effluent management/reduction strategy and managing the fish farm effluents to conform to RIPDES requirements.

There are a number of resources available to aid prospective freshwater aquaculturists in Rhode Island in developing an effluent management plan as part of the RIPDES permitting process (e.g. Mugg et al., 2000; Boyd and Tucker, 2014). Strategies to reduce effluent impacts from freshwater aquaculture pond systems include water retention basins and settling ponds (Kouka and Engle, 1996; Boyd and Queiroz, 2001), use of constructed wetland areas prior to discharge into the Waters of the State (Schwartz and Boyd, 1995), and collection and reuse of the waste products (Yeo et al., 2004). Additionally, a considerable number of cleverly engineered aquaculture effluent management alternatives are now available for prospective high-intensity freshwater fish farmers in Rhode Island that might employ ultra-intensive recirculating or partially recirculating tank systems with mechanical filtration and biological filtration systems (e.g. Meade, 1974; Timmons and Ebeling, 2013).

ACKNOWLEDGEMENTS

This publication was funded in part through a subcontract number Z5023207 from the Northeastern Regional Aquaculture Center at the University of Maryland, under grant number 20163850025754 from the U.S. Department of Agriculture-National Institutes of Food and Agriculture (USDA-NIFA). Discussions with Walter E. Eddy, on-site manager of the Carolina Fish Hatchery, RIDEM-Division of Fish and Wildlife is gratefully acknowledged.

REFERENCES

Blaustein, R.A., Y.A. Pachepsky, R.L. Hill, D.R. Shelton, and G. Whelan. 2013. *Escherichia coli* survival in waters: Temperature dependence. *Water Research* 47:569-578.

Boyd, C.E. and J.F. Queiroz. 2001. Feasibility of retention structures, settling basins, and best management practices for Alabama channel catfish farming. *Reviews in Fisheries Science* 9(2):43-67.

Boyd, C.E. and C.S. Tucker. 2014. Chapter 29: Effluents. pp. 383-403. In: *Handbook for Aquaculture Water Quality*. Available through World Aquaculture Society, Baton Rouge, LA. 439 pp. ISBN 978-0-692-22187-7.

Brockway, D.R. 1953. Fish food pellets show promise. *Progressive Fish-Culturist* 15:92-93.

Eddy, Walter E. 2018. Personal communication to M.A. Rice at Carolina Fish Hatchery, Richmond, Rhode Island (23 Aug 2018).

Kouka, P.J. and C.R. Engle. 1996. Economic implications of treating effluents from catfish production. *Aquacultural Engineering* 15:273-290.

Meade, T.L. 1974. Technology of closed system aquaculture of salmonids. Marine Advisory Service Technical Report no. 30. Rhode Island Sea Grant College Program, Narragansett.

Mugg, J., A. Serrano, A. Liberti, and M.A. Rice. 2000. Aquaculture effluents: A guide for water quality regulators and aquaculturists. NRAC publication no. 00-003, Northeast Regional Aquaculture Center, University of Maryland, College Park. 12 pp.

Pachepsky, Y. A. and Shelton, D. R. 2011. *Escherichia coli* and fecal coliforms in freshwater and estuarine sediments. *Critical Reviews in Environmental Science and Technology* 41:1067-1110.

Providence Evening Bulletin. 1955. This 'farm' raises trout. *Providence Evening Bulletin*, South County-Westerly edition Oct. 26, 1955, p. 1

Providence Sunday Journal. 1921. South County boasts of country's largest trout hatchery. *Providence Sunday Journal*. March 13, 1921, sec 5. p 1.

Rhode Island Department of Environmental Management Office of Water Resources. 1984. Regulations for the Rhode Island Pollutant Discharge Elimination System. Promulgated June 26, 1984; Amended October 7 2018 (https://rules.sos.ri.gov/regulations/part/250-150-10-1)

Rice, M.A. 2010. A brief history of the American Fish Culture Company 1877-1997. *Rhode Island History* 68(1):20-35.

Schwartz, M.F. and C.E. Boyd. 1994a. Channel catfish pond effluents. *The Progressive Fish-Culturist* 56:273-281.

Schwartz, M.J. and C.E. Boyd. 1994b. Effluent quality during harvest of channel catfish from watershed ponds. *The Progressive Fish-Culturist* 56:25-32.

Schwartz, M.F. and C.E. Boyd. 1995. Constructed wetlands for treatment of channel catfish pond effluents. *The Progressive Fish-Culturist* 57:255-266.

Timmons, M. B., & Ebeling, J. M. 2013. Recirculating Aquaculture. Ithaca Publishing Company, Ithaca, NY. 805pp.

Yeo, S.E., F.P. Binkowski, and J.E. Morris. 2004. Aquaculture Effluents and Waste By-Products Characteristics, Potential Recovery, and Beneficial Reuse. NCRAC Technical Bulletin no. 6. North Central Regional Aquaculture Center, Iowa State University. http://lib.dr.iastate.edu/ncrac_techbulletins/6