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Restoration Aquaculture: Reconciling Aquatic Creatures and Ecosystems to Enhance Fruitfulness for All

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In the beginning when God created the heavens and the earth and the Spirit of God hovered over the waters, everything was aquaculture. God was creating out of a watery chaos an ordered and good world. For six days God created before saying, "Let us create A'dam *in our image, male and female let us create them." Over the course of history, humans have been fruitful, but other creatures' fruitfulness has been reduced by the deeds of nearly 10 billion humans on the planet. Among problems are energy use, reduction of habitat, loss of species, and the harmful results of producing food. In* God's Good World—Reclaiming the Doctrine of Creation, *Jonathan Wilson articulates a "doctrine of creation" that invites Christians to consider what justice for all God's creation might entail, including all humans and other species. At this juncture, how can we approach restoration of order and goodness? Genesis 2:15 tells us to* shmar *and* abad *– protect and serve – creation. Jesus the great restorer charges us to care for "the least of these" (Matt. 25:40): people with limited food, water, and housing. Wilson would want us to add caring for the least of the newts, nutrients, and neutrons. In this article, we explore aquaculture for food, including species such as alligators and sturgeon; ecosystem restoration, including aquaponics coupling fish and plants; and reef systems that host many species. We contend that wisely managed restoration can provide for humans while also caring for creation, enhancing justice for this interconnected and intricate creation that isn't just good but is very good.*

Keywords: aquaculture, conservation, creation care, ecology, ecofriendly, fruitful, hydroponics, restoration, seafood, sustainability

Aquaculture is the culture of fish, crustaceans, aquatic plants, and other aquatic organisms, typically for direct or indirect use by humans, most commonly as a component of food. Aquaculture is the fastest-growing protein sector in the world, growing at 6% annually over the last 50 years.[1] It has the potential to sustainably produce healthy, high-quality protein, efficiently providing food needed for growing human populations. In this article, we examine its potential to help individuals and cultures remain faithful to provide for the most vulnerable among us while also protecting and serving all of God's good creation (Gen. 2:15).

Agriculture and aquaculture have both greatly benefited humanity by providing food; but both have also significantly damaged the environment by destroying habitats, depleting resources, and polluting air and water. We believe that acting justly with God's help we can wisely practice aquaculture and judiciously use technology to bring about flourishing within all of creation. We will explore this theme as applied to aquaculture, aquatic species, and habitat conservation.[2]

Fish have been a significant part of many human cultures over millennia. Examples include the Aztec "floating gardens" or *chinampas* which produced plants and fish for a vibrant culture.[3] Hawai'ian *ioko i'a* were historically used to enhance fish availability.[4] These fish enclosures held and grew fish, and likely also enhanced nursery habitat for young fish. Chinese systems often fertilized ponds with waste from land animals (e.g., chickens, pigs) and produced fish that grazed on the resulting algae.[5] Europeans and other cultures around the world have produced fish in ponds that also served as water reservoirs to enhance sustainability.[6] However, aquaculture on the current scale is a recent phenomenon, with a dramatic increase in production since 1960. As of 2022, aquaculture now produces more seafood than all the wild-caught fish from oceans, rivers, and lakes in the world.[7]

Aquaculture exists, is growing quickly worldwide, and has advantages of efficient conversion of feed into protein, but it is becoming a massive enterprise that poses environmental threats, including waste nutrients, use of water, fish feed costs, and energy.[8] Worldwide we now consume more aquaculture products than beef.[9] The data suggest that this may be a good thing as fish are approximately ten times more efficient than cows at converting feed to protein; in addition, aquaculture products may have better health benefits. However, while many researchers are improving efficiency and sustainability of aquaculture, more work is needed; a strong ethical approach must be made to maintain both production and sustainability. This is particularly imperative in light of damage from aquaculture in some locations. Specific long-held opposition to aquaculture has been lessened recently in some areas due to the positive benefits of filter-feeding shellfish (e.g., oysters) and aquatic plants/macroalgae.[10]

Other problems have not been well addressed, leading to greater opposition when the scale of operations has increased. One concern is that fish diseases and parasites from aquaculture may affect wild fish that come close to culture areas where aquaculture occurs. For example, parasitic sea lice may be passed from cultured fish to wild fish causing a reduction in wild fish.[11] Work on aquacultural diseases and parasites has been active in the last decade. Another point of dispute is aquaculture that does not consider the ecosystem (often driven largely by "perverse" economic incentives). In Asia, South America, and elsewhere, coastal mangrove forests were destroyed over large areas to make room for shrimp aquaculture.[12] The shrimp were largely exported to wealthy countries, but the mangrove losses proved painful not only from the loss to an ecosystem but also from the loss of coastal protection. Studies have shown that healthy mangrove forests can protect communities from tsunamis and coastal storms, saving lives while providing habitat for fish.[13] In addition, the shrimp are generally not used locally, so this cannot be argued to be "providing protein to the poor."

However, one strong driver of the growth of aquaculture as well as agriculture is that the human population is larger than it has ever been, and it would be inhumane to allow people to starve.[14] As our population approaches 10 billion, we must care for all people. On the other hand, if we affect our wild species too much, we are damaging creation. Can we grow aquaculture in a responsible way while feeding our growing world? In order to address this question, we must look beyond science to God's design for restoration of a fallen creation.

Athanasius, in the classic *On the Incarnation*, writes:[15]

> We will begin, then, with the creation of the world and with God its Maker, for the first fact you must grasp is this: the renewal of creation has been wrought by the Self-same Word who made it in the beginning. There is thus no inconsistency between creation and salvation … for the One Father has employed the same Agent for both works, effecting the salvation of the world through the same Word Who made it at the first.

This observation from historic Christianity reminds us that Christians have acknowledged restoration of the world as a consistent part of Christian faith for centuries.

In his book *Systematic Theology,* Robert Jenson suggests that "the most obtrusive feature of the priestly creation narrative is the drumbeat rhythm … And God said, 'Let there be …, and there was …'"[16] Just as the story's form has order, so too has the world the Lord creates. In other words, space and time are ordered as God speaks within the narrative and without. And what God speaks into space-time is also good.

This goodness plays out over the days of the creation narrative. God separates the light and the dark, the space above and below, the waters and land, and then fills the spaces with creatures that are good. At the end of each day, the Lord declares that what has been made and ordered is good. Most significant for our purpose here is the word of blessing in Genesis 1.

> And God said, "Let the waters swarm with swarms of living creatures, and let birds fly above the earth across the expanse of the heavens." So God created

> the great sea creatures and every living creature that moves, with which the waters swarm, according to their kinds, and every winged bird according to its kind. And God saw that it was good. And God blessed them, saying, "Be fruitful and multiply and fill the waters in the seas, and let birds multiply on the earth." (Gen. 1:21–22, ESV)

God makes, orders, and blesses the world with a future of abundance. The creatures of the sea are indicated here no less than three times.

Having made, filled, and blessed, the Lord continues to make and order and bless. On the sixth day, humans are made in God's image and are also blessed. Here the speaking turns to conversation as the man and woman are given authority and are commanded to protect and to serve.

How do we understand the right and just use of the authority given to us in a world that is blessed and at the same time broken by sin and filled with sinners? Douglas John Hall in *Imaging God: Dominion as Stewardship* suggests first that "image" is a verb: we are to actively "image" God in all that we do in God's world. He goes on to make a Christological clarification:

> Taking the Lordship of Jesus as an authentic model for understanding our human relation to the natural order means that dominion is expressed not as mastery but as service—sacrificial service of the others with and for whom one is responsible. Thus, the concept of dominion as stewardship eschews any idea of ownership or superiority in relation to nature, yet assumes a special accountability for its welfare.[17]

This definition of dominion as stewardship makes sense as we read the whole of the biblical story backwards from Jesus to Genesis. It helps us see that we are made and remade to use our capacity and communities for the good of all creation through caregiving and service. Stewardship that is faithful is not about getting and grabbing, using and abusing, but it is humble service within a world that God makes and orders and blesses.

This Christological clarification also allows us to continue to read the narrative and explore the theme of stewardship and blessing through various biblical covenants. For example, the Abrahamic covenant, in Genesis 12:2–3, clarifies that God will bless Abraham, make him a nation, and through him bless all the nations. The primary point is obvious: God blesses his creation and blesses his people not for special rights but for a special service of blessing others.

As we read the whole Bible in light of Jesus, how do we think about this kind of service in relationship to the complex systems of aquaculture? Jonathan Wilson in *God's Good World: Reclaiming the Doctrine of Creation* makes the argument that the original creation was "good," even before the creation of humans "in God's image," and that Jesus reflects this "earthy" kind of goodness, coming to care for and restore humans and creation.[18]

From this starting point Wilson considers a range of "earthy" topics including sexuality, technology, food, water, and creation care. Throughout the book, Wilson tries to clarify a driving "why." As noted earlier, Wilson puts forward a robust notion of justice or right relationship that could drive a humble servant-like attempt to steward God's good world for the good of others. The main point is that we have been created and blessed and given the authority for this kind of good work that cares for the least and the lost as well as the lichen and the lionfish.

If we hear all of this and pause, we might find a way forward as we listen to one of Jesus's most famous parables. In Luke 10, Jesus tells the story of the unlikely enemy who turns into a hero. He images Jesus by stopping, caring, mending, and restoring the body of his neighbor. In and through this good work, the Samaritan restores the one who has been used and abused by the power of those who came before!

When we stop, care, mend, and restore, we are using our God-imaged capacity in the way of Jesus, moving a broken creation toward "shalom," a kind of Godly peace, marked by harmony that overflows with blessing. In musical harmony, more than one note is sung at the same time. Each singer must listen to the other, but sing their own part in a way that complements, adds to, and makes more beautiful the notes of others. In what follows, we want to sing a few scientific songs because we believe that they carry the melody and harmony of restoration, stewardship, and creation care. They are hopeful stories, which we can tell with humility: they sound a lot like God's original aquaculture story.

Practical Aquaculture Applications: Culture and Restoration

Alligator Culture and Restoration: A Success Story

The first is the story of the alligator, a native North American reptile that was once a dominant predator in swamps and coastal areas of the southeastern US and

Mexico. Over several centuries, these populations were decimated by hunting, habitat loss, and human activities such as shipping and industrial pollution. In 1967, alligators were declared an endangered species under a law that preceded the Endangered Species Act (ESA).

In this period, a group of visionary researchers conceived the concept of trying to restore this species while also growing them as an aquacultured species. Several decades of scientific studies and discussion of conservation and aquaculture rules led to a decision in the 1970s that allowed the collection of eggs and culture of the resulting juveniles in aquaculture facilities. The agreement was that this would be supervised by representatives of both conservation and agriculture agencies overseeing harvest, culture, and eventual release of a percentage of resulting animals to the wild. During the early part of this period, for every 100 eggs collected, fifteen animals would be released at 1-meter length; at this size, survival is very high.[19]

Over the following decades, populations of wild animals rebounded, and the commercial alligator culture industry, now valued at over $77 million annually, was developed.[20] Both the ecosystem and the regulations have changed as restoration has proceeded. In short, these animals are no longer endangered.[21] The culture industry has been an economic success, and the secondary effects of the wild alligators have been felt in the ecosystem. As in other areas where predators have been re-introduced, vegetation has flourished as excess herbivores have been reduced. In Louisiana, alligators prey upon the invasive nutria, *Myocastor coypus*, introduced 100 years ago from South America. This invasive species has been reduced, and marsh plant health has improved, providing better stability for the marshes and some additional protection to humans as these marshes can reduce wave and storm energy better, even enhancing carbon sequestration, as the plants recover.[22] Shalom, harmony, and balance have been restored, with unexpected blessings as a part of the results.

Sturgeon Conservation, Culture, and Restoration

Another candidate species for culture and conservation is the Atlantic sturgeon *Acipenser oxyrinchus*. Sturgeon are ancient and unique creatures with diamond-shaped scales or scutes that armor and protect the fish. This species was once widespread but now almost all sturgeon species are either endangered or effectively extinct.[23] Perhaps a set of well-designed experiments could provide improved insights to allow one or more native sturgeon species to be restored while valuable aquaculture products are produced. Could we protect and serve—*shmar* and *abad*—the species while restoring a spirit of *shalom* in the Atlantic coastal ecosystems?

To explore what might be required for this we consider culture of two sturgeon species that are currently heavily cultured for caviar, *Acipenser baerii* (31%) and *A. gueldenstaedtii* (20.4%).[24] Author Hall has worked with *A. gueldenstaedtii* in North Carolina (it is native to Eurasia). This is a fish highly valued for caviar. Could a native North American species (e.g., Atlantic sturgeon *A. oxyrinchus* or shortnose sturgeon *A. brevirostrum*) be cultured for caviar? Could the financial incentives be coupled with an agreed-upon release scheme? Ideally, this would take place in concert with habitat restoration. Multiple agencies as well as research personnel would be needed. Agricultural, aquacultural, environmental, and water management agencies; universities; and research institutes as well as industry participants,

Figure 1. *Alligator mississippiensis* thrives in wetland ecosystems and, as an apex predator, contributes to overall wetland health. They are also cultured for their valuable hides and meat. (Photo: Steven Hall, 2025)

farmers, and community members could be involved. A similar set of partnerships helped move alligators from endangered to thriving over previous decades, and such partnerships could help restore sturgeon while enhancing related aquaculture production.

The effort would necessarily be multi-decade. It would require a longer-term source of funding (possibly a long-term public–private partnership), but with the hope that eventually most costs would be borne by the industry which could also grow with a "local, sustainable caviar" option. To do this, we need both habitat and fish, and we must address a range of challenges. There are also concerns about the survival of small sturgeon when released.[25] This suggests that we should grow fish to a somewhat larger size in "safe" captivity, and then transition them to the wild when their survival is higher—following methods similar to the current rules on alligators (e.g., release a known percentage at 1-meter length).

A series of studies is needed to address these factors:

1. habitat restoration—ideally in areas optimal for sturgeon thriving so that when released, fish have an acceptable chance of survival and fruitfulness;
2. improved understanding of breeding and early life stage—to enhance health and genetics for release;
3. legal aspects—local and global laws (e.g., US Endangered Species Act, International CITES agreement) may properly constrain transport of fish but may also limit current restoration efforts;[26] and
4. time—since sturgeon are slow growing, these efforts must be planned over decades to allow time for both culture and development of wild populations.

Each of these aspects encompasses potential theological and ethical considerations; each requires effort and resource input.

With all these challenges, it is tempting to ask, "Is this really the calling of Christians?" We suggest that this very much is a Christian calling. We are called to love and care for "the least of these." This includes people and creatures, especially those with no ability to speak for themselves. We see this as an example of servant leadership as the body of Christ carries out this work. There might also be unexpected blessings that the sturgeon provide that we do not yet realize, but our calling is to care for them; to protect and serve them; to conserve, preserve, and ultimately restore them and their habitat while also providing for humans.

Jesus, in his teaching and life, "raised the bar," calling us to serve sacrificially. Over many centuries, the body of Christ, the church, despite many imperfections, has influenced the world. Jürgen Habermas, who described himself as a "methodological atheist," acknowledged in his book with Pope Benedict: "The direct legacy of the Judaic ethic of justice and the Christian ethic of love is universalistic egalitarianism, from which sprang the … ideals of freedom, human rights and democracy."[27] Even those who are not Christians themselves may be favorably affected by the service and protection of the body of Christ.

Restoring single species can enhance overall ecology as seen in the case of alligator culture and restoration. Ecosystem restoration is important to enhance efforts to restore sturgeon populations. Ecosystems must be reasonably healthy to allow for fruitfulness of the species we seek to restore. Two areas in which an aquatic restoration approach may help restore entire ecosystems include aquaponics and reef restoration. We will explore these next.

Marine Aquaponics as a Path for Restoration and Abundance

Aquaponics focuses on culture of aquatic species (fish, shellfish) with plants and good bacteria, using nutrients from the fish to fertilize the plants and letting the plants and other species filter the water for the fish. Marine aquaponics may use brackish or salty water—both plentiful at coasts around the world—and may be a partial solution to environmental and food security challenges. Rooted in principles of ecosystem sustainability and balance, marine aquaponics aligns with the biblical concepts of stewardship and restoration. Ezekiel 47:9 and Deuteronomy 28:12, 23–24 provide a theological and ethical framework for understanding the role of aquaponics in restoring aquatic ecosystems and ensuring fruitfulness for all. By integrating advanced technologies with divine principles of care for creation, marine aquaponics emerge as one pathway to sustainable development and ecological balance.

Restoring aquatic ecosystems has become a critical global challenge in the face of overfishing, pollution, and climate change. Aquaponics offers an innovative approach to addressing these challenges by integrating aquaculture with hydroponics (growing plants in watery nutrient solutions) in order to create closed-loop systems that simulate natural ecosystems. As Ezekiel 47:9 (NIV) says, "Swarms of living creatures will live wherever the river flows. There will be large numbers of fish because this water flows there and makes the salt water fresh; so where the river flows everything will live." This text highlights the role of water, where life thrives in the presence of flowing water. The picture echoes the sentiment that the goal of marine aquaponics is to rejuvenate the aquatic ecosystem and enhance biodiversity by ensuring that the water flowing out of the production system is clean and functional. Biblical stewardship focuses on key scriptural passages highlighting humanity's responsibility to care for creation and the consequences of neglect. The healing of ecosystems is like the river in Ezekiel's vision, which transforms salt water into fresh water, literally and figuratively. Marine aquaponics systems promote rehabilitation of aquatic environments by cycling nutrients and maintaining water quality, and by emulating natural processes that sustain life and create fruitfulness.[28]

Marine aquaponics brings Ezekiel's vision to life: "swarms of living creatures will live wherever the river flows" when fish waste nourishes the plants, and plants filter water, ensuring sustainability and productivity while nitrifying bacteria convert the toxic wastes (ammonia, NH_3) into a usable form (nitrate, NO_3^-) for plants as nutrients.[29] Abundance is the original design of God for humans to manage and enjoy alongside stewardship and obedience. Deuteronomy 28:12 says, "The Lord will open the heavens, the storehouse of his bounty, to send rain on your land in season and to bless all the work of your hands. You will lend to many nations but will borrow from none."

In contrast, negligence and disobedience result in scarcity and destruction. Deuteronomy 28:23–24 states, "The sky over your head will be bronze, the ground beneath you iron. The Lord will turn the rain of your country into dust and powder; it will come down from the skies until you are destroyed." This covenant framework was first heard in ancient times but also relates to environmental degradation in modern times. We were made not to destroy creation but to protect and serve. Ezekiel reflects God's intention for creation to be fruitful and grow in abundance. Aquaponics creates a micro-ecosystem that can allow us to understand interactions between creatures; it may also be a tool for restoring larger ecosystems. Aquaponics embodies a divine purpose, similar to the vision of Ezekiel, by fostering life and addressing food security challenges. While the "bronze sky" and "iron ground" reflect

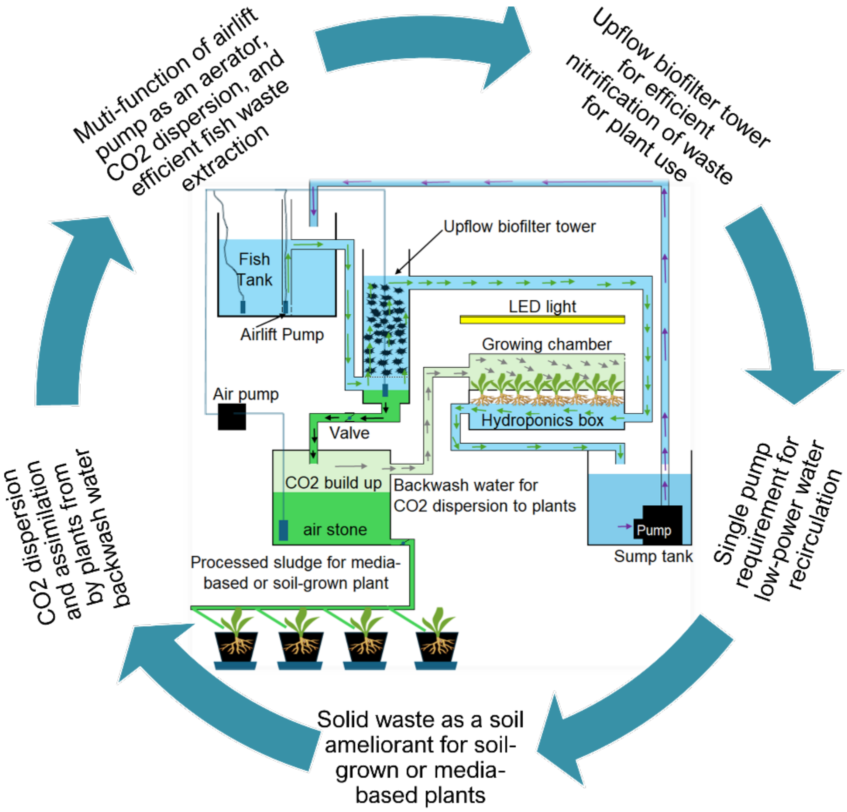

Figure 2. Schematic diagram of a marine aquaponics system, integrating fish farming (aquaculture) and hydroponic plant cultivation within a recirculating setup. The water circulation in the aquaponics system signifies circular blessings and ecosystem reciprocity as modeled in Deuteronomy (giving, receiving, and sharing). Nutrients cycle efficiently, benefiting both fish and plants, while humans reap the rewards and the environment gains through reduced pollution, improved water quality, and enhanced ecosystem balance.

the environmental consequences of exploitation and neglect, aquaponics offers a pathway to restoration by mitigating the effects of overfishing, nutrient runoff, and habitat destruction.[30]

Figure 2 is a schematic diagram for a sustainable ecosystem in marine aquaponics. By integrating aquaculture with salt-tolerant plant cultivation, this system seeks to emulate natural ecosystem processes to achieve efficient nutrient recycling, reduced environmental impact, and enhanced productivity.[31] Just as Deuteronomy speaks of rain as a blessing that ensures productivity, a marine aquaponics system relies on thoughtful design to emulate natural ecosystems. Obedience to principles of God's design ensures the system's productivity, turning limited resources into abundant outputs (fish, plants, and clean water).[32] The system reflects a harmonious balance, parallel to how obedience to God brings blessings. The principle of blessings for diligent labor aligns with the care and innovation required to maintain marine aquaponics systems. Proper management of nutrients, salinity, and biodiversity mirrors the faithfulness expected in the stewardship of God's creation. This concept ensures that all elements traditionally considered "waste" within the system are valorized and repurposed, serving as fertilizers for plant growth or as CO_2 to support plant assimilation, maximizing resource efficiency and sustainability.[33]

Figure 3. A laboratory scale marine aquaponics with hybrid striped bass and salicornia which can be utilized in urban areas. The hybrid striped bass (*Morone saxatilis*) is a key species along the Atlantic coast experiencing significant population fluctuations due to overfishing, habitat loss, and environmental changes. Breeding being done at North Carolina State University by Dr. Benjamin Reading and colleagues uses techniques such as "mixed garden" breeding to maintain healthy genetic diversity.[35]

Easing Pressure on the Ocean Through Urban Aquaponics

While aquaponics may produce plants or fish that can be used to restore aquatic and coastal ecosystems directly, numerous small-scale urban aquaponics systems can significantly reprieve ocean ecosystems by reducing the demand for wild-caught fish and mitigating nutrient runoff that damages marine environments. These systems alleviate pressure on aquatic resources and create opportunities for species restoration. Marine aquaponics systems, in particular, offer a promising avenue for conserving species nearing extinction. These systems may be capable of producing larvae and fingerlings or coastal plants for use in restoration efforts. This innovative integration of conservation and sustainable aquaculture holds immense potential for protecting marine life while addressing global food security challenges. Figure 3 shows a closed-loop recirculating marine aquaponics prototype with hybrid striped bass and salicornia (*Salicornia bigelovii*) grown in a controlled environment. Salicornia is a halophytic plant that can contribute to sustainable agriculture in saline environments. It has many uses, including food, biomass fuel, pharmaceuticals, cosmetics, and ecological restoration, making it a valuable resource for addressing global challenges.[34] Salicornia is an effective root nitrifier and nutrient absorbent (fig. 4), preventing excess nutrients from being released into the environment.

Figure 4. The root nitrification of salicornia plays a critical role in marine aquaponics by absorbing excess nutrients from fish waste, effectively preventing water pollution and mitigating environmental damage.

By integrating fish cultivation with hydroponic plant production in urban settings, recycling resources are optimized while minimizing environmental damage.[36] This approach supports local food production and lessens reliance on overfished marine species, contributing to the recovery of wild fish populations. Furthermore, urban aquaponics eliminates the need for artificial fertilizers, reducing the risk of nutrient runoff that can lead to eutrophication and harmful algal blooms in coastal waters.[37] By fostering sustainable food systems within cities, urban aquaponics represents a practical and scalable method for protecting marine biodiversity while addressing the growing demand for food in urbanized areas. Restoration via aquaponics can produce both food and other products, and it can also help people see the ecosystem restored to fruitfulness. Another set of technologies that directly affects ecosystems is ecologically friendly artificial reefs.

Habitat and Species Restoration via Ecofriendly Reef Systems

As mentioned in previous sections, both species *and* habitats must be restored together. If we release young fish into a compromised ecosystem they are likely to die. So, finding ways to restore ecosystems is critical. Ironically, many of our efforts to "protect" ourselves and other species at the coast result in "hard" infrastructure such as seawalls and jetties. These are not biofriendly and also tend to destroy or limit natural coastal habitat that is critical for young fish. One approach is to provide various forms of artificial habitat or biofriendly coastal reefs. One specific example is produced via a unique biofriendly 3-D printing technique by a company called Natrx.[38] These artificial habitats, along with others made by similar technologies, are then embedded in coastal areas to grow natural organisms, providing protection for breeding and early life stages.

Over time, these reefs transition from artificial ecofriendly concrete or rock structures to growing various encrusting organisms (oysters, barnacles, algae, plants) which allow them to eventually become natural parts of the coastal environment (fig. 5). They provide refuge for young fish; food for crustaceans, algae, and shellfish to clean the water; and protection to adjacent coastal plants. They are semipervious to water, with various openings provided for small creatures to grow on or move through, providing protective habitat, broodstock grounds, and hunting grounds for a variety of species.

Figure 6 shows what can happen in a single year. The original structures (left) have been colonized by oysters, algae, plants, and other creatures (center), providing additional habitat for fish and other aquatic creatures, as well as protecting vulnerable coastal habitat (right), allowing native species to recover and further enhance the ecosystem. This is a different form of aquaculture—we are culturing aquatic organisms and, while some

Figure 5. East River Project Photos. (Left) installation on tidal mudflats 2022 and (Right) growth and protection of shoreline 2024. (Courtesy of Natrx Inc.)

of these might be harvested for food (e.g., oysters), depending on the situation, they might be left to provide additional services, including biological and ecological benefits for other parts of the coastal system.

It should be noted that these specific techniques are most appropriate in certain habitat—for example, where encrusting organisms such as oysters are likely to grow at appropriate salinity, temperature, and other relevant conditions. As a result, sites must be considered carefully and relevant techniques applied based on local environmental conditions. Nevertheless, these appear to hold promise of protecting coastal habitat that may be threatened by larger coastal storms, while minimizing cost and providing additional benefits for local species. Many of these types of emplacements have been made in the US and around the world and more are planned. These are one more way that a form of aquaculture can assist in restoring God's creation.

We have explored ways that aquaculture, done well and creatively, can encourage restoration of various species and ecosystems. This is a somewhat idealistic view, but it is critical to consider that "we are God's handiwork, created in Christ Jesus to do good works God has prepared for us to do …" (Eph. 2:10). We have covered a number of specific practical areas in which this is already happening or could happen in the near future. These may allow us to consider other areas of aquaculture, agriculture, and human culture more broadly in which Christians, in particular, can consider restoration and reconciliation as part of our callings, fulfilling our roles to protect and serve God's creation, providing food and materials for people while restoring God's creation.

Conclusions and Future Work

In conclusion, we are called to join the Lord in restoring his good creation, blessing other humans and other species, and carrying out his calling to *shmar* and *abad* (Gen. 2:15) creation. As we do this with these and other aquaculture approaches, we find food production may be linked to habitat and much else, and even to our Creator and Restorer. Revelation 21 speaks of a "renewed heaven and earth …" Theologically, there are a variety of interpretations, but the context of "renewal" is clear. In the next chapter (Rev. 22), an angel shows the author "the river of the water of life, as clear as crystal, flowing from the throne of God and of the Lamb down the middle of the great street of the city. On each side of the river stood the tree of life, bearing twelve crops of fruit, yielding its fruit every month. And the leaves of the tree are for the healing of the nations" (Rev. 22:1–2). Here we have a depiction of renewal, fruitfulness, and healing including humans, God, water, and living creatures.

Future work should also address challenges unique to our time and culture. The "how" of this work is important. Yes, we should produce aquatic food for all. Yes, we should care for and restore God's creation to allow for fruitfulness for all. Yet the way we do this work matters too. Science and technology can be excellent tools to carry out our callings, or can be ways to distance ourselves from caring for the least of these. Ethical approaches to technology are critically important.[39] Previous work has explored these themes and further work is needed as technology, robotics, and artificial intelligence advance. In some areas of aquaculture, robotic boat systems have been developed using autonomous surface vehicles (ASV) designed to

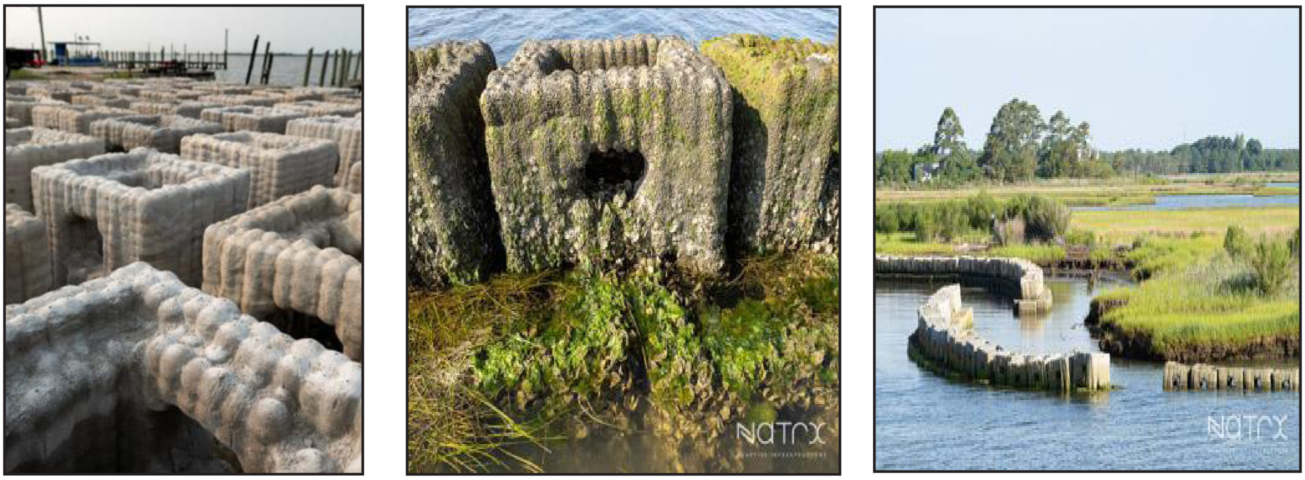

Figure 6. Hog Island Photos: Installation 2023 (left); growth of oysters, algae, spartina, and other species 2024 (center and right photos) (courtesy Natrx Inc.)

reduce bird predation on open-air aquaculture ponds; in addition, there are fleets of these aquatic robots that provide mobile sensor platforms and potentially mobile actuators.[40] Wise use of these and other forms of technology in aquaculture can help find ways to provide for humans, enhance human decision making, and provide high-protein foods while restoring healthy ecosystems. One possible approach would be to use some of these types of systems to observe and manage sturgeon and habitat conditions during restoration efforts.

Another modern reality: economics drives much; wealth may be the greatest idol of our time, but true values are real and important. Considering values (not only dollars but also environmental flourishing, human health, and other positive values) and, where possible, adding value, is important and may guide aquaculture practitioners and consumers to consider how to make wise decisions related to fish and aquatic products. Value-added seafood encompasses aquatic products that have been enhanced to improve food safety, provide convenience, increase quality, offer good taste and affordability.[41] Furthermore, value-added seafood drives sustainability by emphasizing reduced environmental damage, instituting best industrial practices, and promoting initiatives such as fisher-to-consumer marketing and product traceability.[42] Several programs and organizations (e.g., the Food and Agriculture Organization of the United Nations and the Marine Stewardship Council) encourage companies to curtail their environmental impact through implementation of industry certifications and standards such as Best Aquaculture Practices.[43] Consumers can check for these certifications, encouraging the seafood industry to improve long-term sustainability and restoration efforts worldwide. Buyers can also buy local seafood and ask how it was caught or produced.

There are many challenges that must be addressed in aquaculture as in our other endeavors. Developing culture techniques that minimize disease and pollution are critical. It is imperative that we find ways to restore aquatic ecosystems while providing food, if we are to avoid either hunger or destruction of God's creation. Ultimately, we are called to serve in our times and places by restoring and sharing shalom with humans and other creatures. Justice and mercy are both important; food for humans and care for God's creation are each necessary. We propose responding to God's calling on our lives, as Christ's body, made in the image of God, to care for God's creation, with this focus on God's aquatic creation, to restore it in our location, in our local way, in faithfulness to his grace in our lives.

About the Authors

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Notes

[1]Food and Agriculture Organization (FAO, hereafter), *The State of World Fisheries and Aquaculture 2024: Blue Transformation in Action* (FAO, 2024), https://openknowledge.fao.org/items/06690fd0-d133-424c-9673-1849e414543d; and World Bank, "Fish to 2030: Prospects for Fisheries and Aquaculture (English)," (World Bank Group, 2013), Agriculture and environmental services discussion paper; no. 3, http://documents.worldbank.org/curated/en/458631468152376668/Fish-to-2030-prospects-for-fisheries-and-aquaculture.

[2]FAO, *The State of World Fisheries and Aquaculture* 2024; and World Bank, "Fish to 2030."

[3]Catalina Rey-Hernández and Inge Bobbink, "Chinampas Agriculture and Settlement Patterns: The Contemporary Relevance of Aztec Floating Gardens," *Blue Papers* 1, no. 2 (2022): 90–99, https://doi.org/10.58981/bluepapers.2022.2.09. This article explores Aztec techniques to manage water, produce food, and maintain resilience in the Valley of Mexico. They cite data that these systems operated as early as 200 BC, and are being considered as examples to use when managing urban aquacultural and agricultural systems today.

[4]Anne Innes-Gold et al., "Restoration of an Indigenous Aquaculture System Can Increase Reef Fish Density and Fisheries Harvest in Hawai'i," *Ecosphere* 15, no. 3 (2024): e4797, https://doi.org/10.1002/ecs2.4797. The article suggests that historic *Ioko i'a* not only held and grew fish but also may have had positive effects on local fisheries by acting as a nursery and protective area for young fish.

[5]Ashleigh J. Rogers, "Aquaculture in the Ancient World: Ecosystem Engineering, Domesticated Landscapes, and the First Blue Revolution," *Journal of Archaeological Research* 32 (2024): 427–91, https://doi.org/10.1007/s10814-023-09191-1. This article suggests that Chinese aquaculture may have started as early as 8,000 years ago, and has been a historic and vibrant activity for many centuries. Incidentally, modern China has been the leading aquaculture producer for at least 20 years, producing some 60% of world aquaculture in 2024.

[6]Ashleigh J. Rogers also explored the history of aquaculture in Roman, medieval European, and other historic contexts. It is clear that aquaculture has been practiced for centuries. However, the scale of modern aquaculture has dramatically increased, and the scale of environmental impacts has also increased dramatically in the last 70 years.

[7]FAO, *The State of World Fisheries and Aquaculture 2024*.

[8]Rosamond Naylor et al., "Effect of Aquaculture on World Fish Supplies," *Nature* 405 (2000): 1017–24, https://doi.org/10.1038/35016500; Rosamond Naylor et al., "A 20-Year Retrospective Review of Global Aquaculture," *Nature* 591 (2021): 551–63, https://doi.org/10.1038/s41586-021-03308-6; Steven Hall, "Raising Food for Thought," *Perspectives on Science and Christian Faith* 72, no. 3 (2020): 131–43, https://www.asa3.org/ASA/PSCF/2020/PSCF9-20Hall.pdf; and Steven Hall et al., "Toward a Theology of Sustainable Aquaculture: Wisely Producing Safe Abundant Seafood While Enhancing Fruitfulness of Aquatic Creatures," *Perspectives on Science and Christian Faith* 76, no. 2 (2024): 107–24, https://www.asa3.org/ASA/PSCF/2024/PSCF9-24Hall.

[9]FAO, *The State of World Fisheries and Aquaculture 2024*.

[10]Rosamond L. Naylor, Susan L. Williams, and Donald R. Strong, "Aquaculture—A Gateway for Exotic Species, *Science* 294, no. 5547 (2001): 1655–56, https://doi.org/10.1126/science.1064875; and Rosamond Naylor et al., "A 20-Year Retrospective Review of Global Aquaculture." In this more recent article, Naylor acknowledged that macroalgae and shellfish can help enhance water quality and could be particularly sustainable forms of aquaculture, potentially contributing to restoration of some habitats.

[11]Mari Lee Larsen, Irja Vormedal, and Knut W. Vollset, "Negative Association of Sea Lice from Fish Farms on Recreational Fishing Catches of Atlantic Salmon," *Journal of Applied Ecology* 61, no. 8 (2024): 1772–83, https://doi.org/10.1111/1365-2664.14712. This article notes that challenges are posed by netpens that may allow pollutants, diseases, or parasites to harm wild populations. The authors also admit that the process is highly variable, with only 4 of 13 areas having measurable associations, as well as acknowledging these are complex systems affected by a wide variety of human and natural effects.

[12]Toiaba Taher et al., "Impacts of Shrimp Aquaculture on the Local Communities and Conservation of the World's Largest Protected Mangrove Forest," *Environmental Science & Policy* 147 (2023): 351–60, http://dx.doi.org/10.1016/j.envsci.2023.07.002. This article explores both conservation (environmental) effects and social effect on local communities in areas where shrimp aquaculture is practiced. They also note that in areas where mangrove forests are protected, there are a number of other benefits.

[13]Saudamini Das and Jeffrey R. Vincent, "Mangroves Protected Villages and Reduced Death Toll During Indian Super Cyclone," ed. Gretchen C. Daily, *PNAS* 106, no. 18 (2009): 7357–60, https://doi.org/10.1073/pnas.0810440106. These authors called the coastal protection capabilities of mangrove forests (against tsunamis and coastal storms) an "undervalued ecosystem service." These plants literally save lives! Aquaculture of shrimp that destroys these forests is not responsible aquaculture.

[14]FAO, *The State of World Fisheries and Aquaculture 2024*; and Steven Hall, "Toward a Theology of Sustainable Agriculture," *Perspectives on Science and Christian Faith* 54, no. 2

(2002): 103–7, https://www.asa3.org/ASA/PSCF/2002/PSCF6-02Hall.pdf.

[15]Athanasius, *On the Incarnation* (Gladdening Light Press, 2023), 7. This edition has a foreword by Robert Falconer; it is a translation of the original, written by St. Athanasius of Alexandria (296–373), in the 4th century. Athanasius was a bishop who helped clarify a number of Christian theological difficulties in the early church.

[16]Robert Jenson, *Systematic Theology: The Works of God*, volume 2 (Oxford University Press, 1999), 5.

[17]Douglas John Hall, *Imaging God: Dominion as Stewardship* (Eerdmans, 1986).

[18]Jonathan R. Wilson, *God's Good World: Reclaiming the Doctrine of Creation* (Baker Academic, 2013), 12.

[19]Mary J. Nickum et al., "Alligator (*Alligator mississippiensis*) Aquaculture in the United States," *Reviews in Fisheries Science and Aquaculture* 26, no. 1 (2018): 86–98, https://doi.org/10.1080/23308249.2017.1355350.

[20]FAO, *The State of World Fisheries and Aquaculture 2024.*

[21]The *Federal Register* (2021) noted that alligators are one notable success of the endangered species act as they have experienced "both drastic decline and complete recovery," https://www.federalregister.gov/documents/2021/01/19/2021-01012/endangered-and-threatened-wildlife-and-plants-regulations-pertaining-to-the-american-alligator#:~:text=The%20American%20alligator%20first%20received,the%20policy%20of%20the%20Act.

[22]Christopher M. Murray et al., "American Alligators *(Alligator mississippiensis)* as Wetland Ecosystem Carbon Stock Regulators," *Scientific Reports* 15 (2025): 3423, https://doi.org/10.1038/s41598-025-87369-x.

[23]Victor Lobanov, Joe Pate, and Alyssa Joyce, "Sturgeon and Paddlefish: Review of Research on Broodstock and Early Life Stage Management," *Aquaculture and Fisheries* 9, no. 6 (2024): 871–82, https://doi.org/10.1016/j.aaf.2023.04.001. Note that "24 of 25 extant species are classified as critically endangered … populations continue to decline, with the extinction of some species considered imminent." They also recognize "the most recent official … extinction was the Yangtze sturgeon in July 2022 …" (p. 871). This argument suggests that finding ways to restore these ancient but unique creatures is a strong calling at this time.

[24]Paolo Bronzi et al. note that five species and two hybrids account for 90% of production. Coauthor of this article, Steven Hall, has experience with *A. gueldenstaedtii*, whose caviar sells for over $100/ounce. See Paolo Bronzi et al., "Sturgeon Meat and Caviar Production: Global Update 2017," *Journal of Applied Ichthyology* 35, no. 1 (2019): 257–66, https://doi.org/10.1111/jai.13870.

[25]Saulius Stakenas and Andrej Pilinkovskij, "Migration Patterns and Survival of Stocked Atlantic Sturgeon (*Acipenser oxyrinchus* Mitchell, 1815) in Nemunas Basin, Baltic Sea," *Journal of Applied Ichthyology* 35, no. 1 (2019): 128–37, http://dx.doi.org/10.1111/jai.13871. The authors noted that young sturgeon stocked into wild habitat had very low survival level, possibly due to commercial fishing. Survival was more successful in rivers, perhaps due to limited fishing. This also should be considered when exploring optimal restoration efforts—perhaps protected rivers might be better places for sturgeon release. See also Lobanov et al., "Sturgeon and Paddlefish."

[26]Lobanov et al. note that with respect to laws (CITES and ESA) some of the laws intended to protect sturgeon actually make it very hard to restore populations to the wild: "Ironically, this stringency tends to discourage efforts to bring aquaculture and restoration together" (Lobanov et al., "Sturgeon and Paddlefish," 872).

[27]Jürgen Habermas and Pope Benedict XVI, *The Dialectics of Secularization: On Reason and Religion* (Ignatius Press, 2007).

[28]Mathilde Eck, Oliver Körner, and M. Haïssam Jijakli, "Nutrient Cycling in Aquaponics Systems," in *Aquaponics Food Production Systems: Combined Aquaculture and Hydroponic Production Technologies for the Future*, ed. S. Goddek et al. (Springer International, 2019), 231–46, available at https://doi.org/10.1007/978-3-030-15943-6_9.

[29]Christopher Pascual, "Optimizing Nutrient Conversion and Recovery in Marine Aquaponics," (PhD diss., North Carolina State University, 2025), https://www.lib.ncsu.edu/resolver/1840.20/45160. This dissertation explains in great detail how these systems operate, and analyzes the enhanced efficiency of these managed ecosystems.

[30]U. Rashid Sumaila and Travis C. Tai, "End Overfishing and Increase the Resilience of the Ocean to Climate Change," *Frontiers in Marine Science* 7 (2020), https://doi.org/10.3389/fmars.2020.00523; and Jiaxin Lan et al., "Harmful Algal Blooms in Eutrophic Marine Environments: Causes, Monitoring, and Treatment," *Water* 16, no. 17 (2024): 2525, https://doi.org/10.3390/w16172525.

[31]Pascual, "Optimizing Nutrient Conversion and Recovery in Marine Aquaponics."

[32]Christopher Pascual et al., "Intermittent Salt Application Enhances Total Soluble Solids of Strawberries (*Fragaria x ananassa*) in Hydroponics," *Discover Plants* 2 (2025): 133, https://doi.org/10.1007/s44372-025-00214-3. In this article, initially with a focus on recovering nutrients (and hence not impacting local ecosystems with excess nutrients), it was also found that slightly salty nutrient laden water made strawberries sweeter. As we seek to hear and follow God's calling to care for his creation and his people, we find, like the Psalmist: "How sweet are thy words unto my taste! yea, sweeter than honey to my mouth!" (Ps. 119:103 KJV). In this case, the result was literally sweeter!

[33]James E. Rakocy, "Aquaponics: The Integration of Fish and Vegetable Culture in Recirculating Systems," paper presented at the thirtieth annual meeting of the Caribbean Food Crops Society, Vol. 30, St. Thomas, U.S. Virgin Islands, 1994, https://doi.org/10.22004/ag.econ.258746; and Baldassare Fronte, Greta Galliano, and Carlo Bibbiani, "From Freshwater to Marine Aquaponic: New Opportunities for Marine Fish Species Production," paper presented at the conference VIVUS–On Agriculture, Environmentalism, Horticulture and Floristics, Food Production and Processing and Nutrition: With Knowledge and Experience to New Entrepreneurial Opportunities, April 21, 2016, Biotechnical Centre Naklo, Strahinj 99, Naklo, Slovenija, pp. 514–21, https://www.researchgate.net/publication/303875126_From_freshwater_to_marine_aquaponic_new_opportunities_for_marine_fish_species_production.

[34]Tanmay Chaturvedi et al., "Salicornia Species: Current Status and Future Potential," chap. 31 in *Future of Sustainable Agriculture in Saline Environments,* ed. Katarzyna Negacz et al. (CRC Press, 2022), 461–82; and A. Karimian, S. H. Pourhoseini, and A. Nozari, "*Persica Akhani* Salicornia as Novel Biodiesel Feedstock Production for Economic Prosperity in Salty and Water Scarcity Areas: Optimized Oil Extraction Process and Transesterification Reaction Using New Magnetic Heterogenous Nanocatalysts," *Renew-*

able Energy 211 (2023): 361–69, https://doi.org/10.1016/j.renene.2023.04.119.

[35]James E. Rakocy, Thomas M. Losordo, and Michael P. Masser, "Recirculating Aquaculture Tank Production Systems: Integrating Fish and Plant Culture," Southern Regional Aquaculture Center Publication 454 (November 1992), https://www.ncrac.org/files/inline-files/SRAC0454.pdf.

[36]Christopher Pascual et al., "Optimizing Light Intensity and Salinity for Sustainable Kale (*Brassica oleracea*) Production and Potential Application in Marine Aquaponics," *Sustainability* 16, no. 23 (2024): 10516, https://www.mdpi.com/2071-1050/16/23/10516. The researchers found that kale, a popular and nutritious green, can grow well up to 8 ppt salinity (a typical salt level for brackish water near the coast), producing nutritious greens, removing waste nutrients, and providing economic incentive to pursue this activity that can care for creation.

[37]L. K. Andersen et al., "Methods of Domestic Striped Bass (*Morone saxatilis*) Spawning That Do Not Require the Use of Any Hormone Induction," *Aquaculture* 533 (2021): 736025, https://doi.org/10.1016/j.aquaculture.2020.736025. This article focuses on breeding techniques that are more "natural" including the "mixed garden" technique to reduce the need for artificial hormones and to maintain good genetic diversity; and Linnea K. Andersen, Neil F. Thompson et al., "Advancing Genetic Improvement in the Omics Era: Status and Priorities for United States Aquaculture," *BMC Genomics* 26 (2025): article 155, https://doi.org/10.1186/s12864-025-11247-z. This article focuses on genetic improvement and includes a range of discussions including (1) "enhancements" such as increased growth rate that are desirable for cultured species; and (2) genetic diversity, critical for the species and longer-term success in culture (and restoration).

[38]Nartx Inc.'s president, Matthew Campbell, is coauthor of this article. Matthew D. Campbell et al., Three-dimensional printing. US Patent 9,962,855, issued May 8, 2018 (for printing customized coastal reefs). This patent produces somewhat "natural-looking" results as shown in figures, but it also allows organic inclusions that may enhance the environment or growth of desired organisms. The website, https://natrx.io, provides a great deal more information and even an approach to their philosophy. While we do not specifically advocate for these particular products over any others, they are a good example of an entire area of "living infrastructure" that is growing as people—Christians and others—recognize the need for more ecologically friendly solutions to such challenges as coastal protection. For background on this growing field, see Steven G. Hall et al., "Growing Living Shorelines and Ecological Services via Coastal Bioengineering," chap. 13 in *Living Shorelines The Science and Management of Nature-Based Coastal Protection,* ed. Donna Marie Bilkovic et al. (CRC Press, 2017), 249–70; and Steven G. Hall, "Bioengineered Reefs to Enhance Natural Fisheries and Culture Eastern Oyster *Crassostrea virginica* in the Gulf of Mexico," in D. Thangadurai, S. G. Hall, A. Manimekalan, and G. Mocz, *Fisheries, Aquaculture and Biotechnology* (Agrobios, 2009), 27–34.

[39]Hall et al., "Toward a Theology of Sustainable Aquaculture," explored the concept of a "sustainable aquaculture" and included discussion of approaches to automation, robotics, and technology more generally.

[40]S.G. Hall and R.P. Price, "An Autonomous Scareboat to Reduce Bird Predation on Aquaculture Ponds," *Louisiana Agriculture* 46, no. 1 (2003): 4–6; Amanda Taylor et al., "Development of an Autonomous Boat for Sustainable Aquatic Plant Biomass Collection," paper 141900179 published by the American Society of Agricultural and Biological Engineers (ASABE) presented at ASABE, July 2014, Montreal, QC, https://doi.org/10.13031/aim.20141900179; and Daniel Smith et al., "Design of a Semi-autonomous Boat for Measurements of Coastal Sedimentation and Erosion," proceedings of a symposium held in New Orleans, LA, December 11–14, 2014, IAHS publication 367, 447–454, https://piahs.copernicus.org/articles/367/447/2015/piahs-367-447-2015.pdf.

[41]Michael Morrissey and Christina DeWitt, "Value-Added Seafood," chap. 13 in *Seafood Processing: Technology, Quality and Safety*, ed. Ioannis S. Boziaris (John Wiley & Sons, 2014), 343–58, https://doi.org/10.1002/9781118346174.ch13.

[42]A. K. Farmery et al., "Food for All: Designing Sustainable and Secure Future Seafood Systems," *Reviews in Fish Biology and Fisheries* 32, no. 1 (2022): 101–21, https://doi.org/10.1007/s11160-021-09663-x.

[43]Taher et al., "Impacts of Shrimp Aquaculture on the Local Communities."

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