The Tomatofish

Fish and tomatoes under one roof

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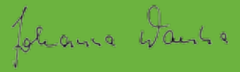
Foreword by Federal Minister Johanna Wanka

The world's population is growing rapidly. At the turn of 2013/2014, the United Nations estimated the global population to be 7.2 billion people. With this growth comes increased consumption of resources, so finding solutions to global challenges such as climate change, resource scarcity, shortage of drinking water, loss of biodiversity, and soil fertility is ever more urgent.

These problems can only be addressed with the support of science. An exceptional example of this is the "Tomatofish" project. This project, which is funded by the German Federal Ministry of Education and Research (BMBF), combines fish and vegetable farming to conserve resources. Its goal is sustainable and climate-friendly food production.

This brainchild of scientists from the Leibniz-Institute of Freshwater Ecology and Inland Fisheries works just as well in the middle of a city as it does in remote regions of the world. The "Tomatofish" provides the means for a sustainable diet for consumers while sacrificing neither consumption nor quality. For this reason, the project was awarded the German Sustainability Award for Research (Deutscher Nachhaltigkeitspreis Forschung) in 2012.

Healthier living, a sustainable economy, preserving the environment – innovative ideas like the "Tomatofish" make these things possible. It is but one example of over 6000 forward thinking projects of the BMBF framework program "Research for Sustainable Development" (FONA), which have provided significant impetus for a climate-friendly and sustainable development and helps to improve the future viability of our society.



Prof. Dr. Johanna Wanka
Federal Minister of Education and Research

The Tomatofish

Fish and tomatoes under one roof

The Tomatofish lives at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB): in a project funded by the German Federal Ministry of Education and Research (BMBF), researchers have developed a method for producing fish and tomatoes under one roof. Tilapia fish and tomatoes have similar environmental needs for growth, for example a preference for warmth. Because these two go so well together, we named the project using the portmanteau "Tomatofish".

The Tomatofish thrives in a greenhouse at the IGB, living inside an interconnected aquaculture and hydroponics facility. This technology conserves resources and is almost emission-free. Details of how the aquaponic system works are provided in the following pages.

Sustainability research that's to everyone's taste!

Germany is a leader when it comes to solving the challenges facing today's society, and the federal government has launched a high-tech strategy to further consolidate that role. Research and development are focused on five areas of need. The "Health and Nutrition" area is devoted to the world's food supply, as developing healthy sustainable food sources requires innovative ideas and solutions. The Tomatofish and other projects are supported within the framework program "Research for Sustainable Development" (FONA). The project shows how pioneering agricultural work also must take into account economic, environmental, and social concerns.

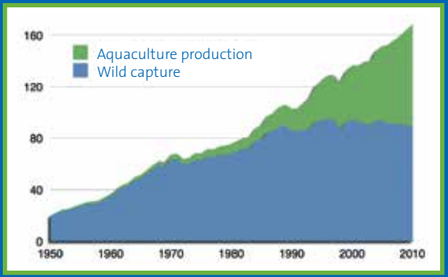
Fish: food of the future

Fish doesn't only taste great, it also has a big advantage over meats like chicken, beef, and pork: when produced in closed recirculation aquaculture systems (RAS), less food and water are needed. Fish emit less carbon dioxide (CO_2) than other animals because they are cold-blooded, and don't need to spend energy regulating their body temperature. Eating fish is also very healthy, because the greater separation between the musculature and connective tissue makes it easy to digest.

Unfortunately, eating wild fish is often not sustainable, because of the overfishing of many fish stocks worldwide. Because of this big demand, fish production through aquaculture is becoming more common. With the right setup, aquaculture has the potential to reduce environmental pressure. Under controlled conditions, it is possible to produce fish in an animal-friendly way, without causing them undue stress.

Natural ecosystems like oceans and inland waters cannot meet the global demand for fish. Fish grown through sustainable aquaculture could help to protect wild fish stocks, natural resources and the environment.

According to the Food and Agriculture Organization of the United Nations (FAO), aquaculture is one of the fastest growing areas of agriculture. The wild catch worldwide has been stagnating, and half of all fish production now comes from farmed fish (see chart). In Germany, around 1.3 million tons of fish are consumed, the majority of which is imported. Only about 3% of this comes from domestic aquaculture. This proportion could be increased through sustainable aquaculture.



(Source: The State of World Fisheries and Aquaculture 2014, FAO)

Good aquaculture vs. poor aquaculture

Intensive aquaculture is often not operated in a sustainable way. For example, excessive input of nutrients can cause considerable strain on ecosystems. In contrast, a closed recirculation system like Tomatofish allows water to be efficiently processed. Drug use is generally unnecessary, because there is nearly no pathogen entry from outside of the facility.

In conventional aquaculture, fish are often fed fishmeal or fish oil pellets. The advantage is that these foods contain polyunsaturated fatty acids. The disadvantage is that the small fish from which fishmeal is made, for example sardines, are then no longer available to the marine ecosystem as food for predators such as bigger fishes or birds.

Alternatives to fishmeal include pellets of fly maggots grown on organic waste, and purely plant-based feed. These alternative feed options offer an optimal diet composition for the fish. At the moment, however, some alternative feedstuffs are not admitted to trading or are relatively expensive to produce.

The reproduction and raising of fish is also studied at the IGB. This small tilapia is about ten weeks old. When it is fully-grown, it will weigh up to three kilograms.

Although some alternative feeds are already available on the market, their production is still quite expensive.

A multistage system passes the waste-water from the fish tanks through a series of filters, where it is processed for the tomato plants.

Aquaponics: an innovative and sustainable cycle

Fish produced sustainably from RAS is an ideal product for consumers concerned about the environmental impact of food production. The Tomatofish system synergistically combines a closed-loop system for fish production with hydroponic plant farming. Tilapia and tomatoes benefit from each other, and both thrive. The system therefore sets a new standard in sustainable production.

The plants absorb the CO_2 exhaled by the fish, and use it to produce oxygen while they grow. When the system is powered by renewable sources like wind, solar, or biomass, the entire system runs with almost no emissions.

The Tomatofish principle can help saving resources on a much larger scale. Closed-loop systems like Tomatofish can be used in areas that are too dry for conventional agriculture, with the necessary heat provided by the local climate. In the northern hemisphere, heat can be in scarce supply, while water is often plentiful. In these cases, waste heat from biogas or cogeneration plants can be used in aquaponics. In this way, thermal energy that might otherwise be wasted is put to good use in heating the water and plant cycle.

The success story

Coffee break with consequences

IGB researcher Prof. Werner Kloas explains in an interview how the Tomatofish was "invented".

Question: Growing fish and vegetables in the same circuit sounds unusual. How did you get this idea?
Werner Kloas: : In September of 2007, eight of the aquaculture researchers from the IGB were sitting together during a coffee break, discussing strategies for advancing aquaculture in Germany. As I recall, the conversation was wide-ranging, from therapeutics for fish to development of circulation systems. Suddenly, our colleague Bernhard Rennert told us about an aquaponic facility developed in GDR times by the former Institute for Inland Fisheries and the Academy for Agricultural Sciences, in which carp and cucumbers were produced together.

That perked up everyone's ears ...
Yes, especially because the dual-circuit facility worked so well: The wastewater from the fish tank was used to irrigate the cucumbers, for which Bernhard Rennert installed a one-way valve, a technical detail that helped to provide ideal growth conditions for both subsystems. This principle is used today in the Tomatofish circuit as well.

Why did you end up switching from cucumbers to tomatoes?
Our coffee break wasn't over yet. We quickly came to the recognition that the idea would work well for tilapia and tomatoes. Tilapia are omnivorous, robust, and grow very quickly. Tomatoes are the country's favourite vegetable, and the IGB researchers love them, too. Although I should say that we've also experimented with other varieties, such as basil, cucumber, and chilies. It was during this same coffee break that I suggested a plan to reuse the water vapor in the system. We recover it through cold traps, and use it as fresh water for the aquaculture unit.

How long did it take to develop from an idea into a concrete project?
It went very quickly. We submitted a project proposal to a BMBF call for applied research in October 2007. The Tomatofish was a perfect fit. We got the go-ahead in December 2007, and the greenhouse was already finished in June of 2008. The project went from idea to implementation in less than a year!

Professor Werner Kloas in the IGB pilot plant.

In March of 2014, the Tomatofish project was awarded the designation "Selected Landmarks in the Land of Ideas". The award was presented by Juliane von Trotha (right) and Dr. Christoph Westerburg (left), who used the opportunity to visit the Tomatofish greenhouse.

The Tomatofish makes waves

The closed system in which the Tomatofish grows and prospers has an official name: Aquaponic System for emission-free Tomato and Fish PROduction, or ASTAF-PRO for short. The special feature of the patented system is that each of the resources is used twice, including nutrients, water, heat and electricity. Tomatoes and fish are produced with virtually no emissions, because the tomatoes use both the nutrient-rich water from the fish tanks and the CO_2 respirated by the fish to grow.

The Tomatofish won the German Sustainability Award in 2012

Because the Tomatofish is such a sustainable idea, it was funded and showcased as a project within the framework of the BMBF's "Science Year 2012 Project Earth: Our Future". In addition, ASTAF-PRO beat out 70 other projects to be awarded the "National German Sustainability Award" by the BMBF's jury in 2012. This annual competition awards projects that find novel and intelligent solutions to urgent problems in energy, nutrition, and resource protection.

The Tomatofish goes international (INAPRO)

The ASTAF-PRO pilot plant at the IGB was only the first step towards testing the Tomatofish idea on a larger scale. The IGB has set the goal of disseminating the technology among potential users worldwide.

In 2014, an IGB proposal to the EU was accepted: The institute is now coordinating a six million Euro project, with 18 partners from 8 countries. In the four-year INAPRO project (Innovative model & demonstration based water management for resource efficiency in integrated multitrophic agriculture and aquaculture systems), four 500 square meter aquaponic demonstration plants will be modelled, built, and evaluated at locations in Germany, Spain, Belgium, and China.

INAPRO will demonstrate the technical and economic feasibility of the Tomatofish system on a larger scale. The aim is to make the Tomatofish ready for serial production, and to convince potential users and investors of its worth. This IGB-developed technology could then be able to contribute to food security in the 21st century.

Tomatofish applied: urban farming, large scale systems, and waste heat recovery

The ASTAF-PRO system is scalable from a "rain barrel" format to a large farm. This means that a wide range of applications is possible, from small hobby plants on a roof terrace or in backyards, to commercial urban farms or large-scale systems in rural areas. The system has great potential in terms of developmental assistance, because small and medium-sized plants can be built to improve self-sufficiency and local development. Another possible application is in coupling aquaponics with other systems, for example at cogeneration or biogas plants. The locally produced electricity, unused waste heat, and resulting CO_2 can be directly utilized in aquaponics. This allows value chains to be lengthened sustainably.

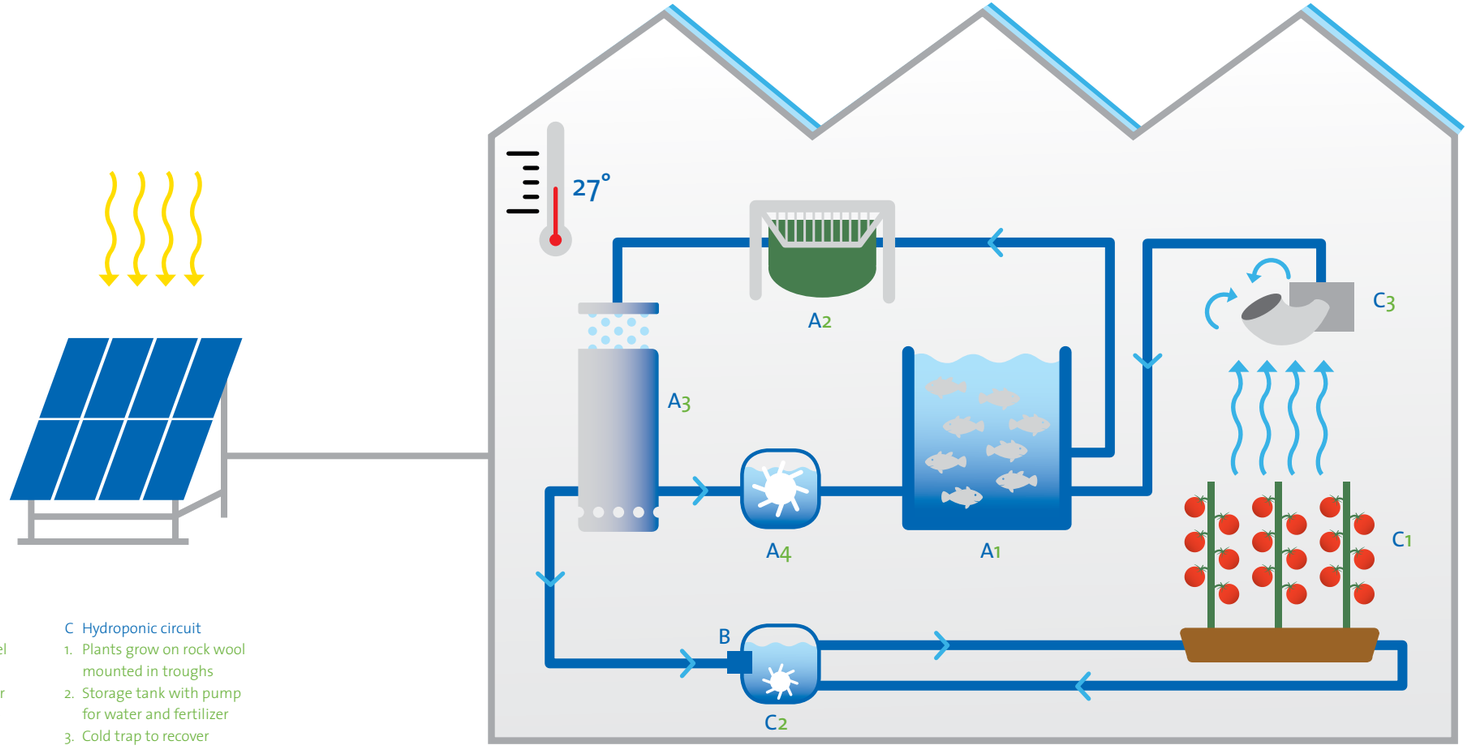
The contact for use of the ASTAF-PRO patent is the IGB partner company agrathaer GmbH. For further contact details please see the imprint on page 25.

The Aquaponic system is scalable from a small format (shown here at FEZ Berlin) up to a large commercial farm.

The technology

Clever switching: the one-way valve

The Tomatofish grows in a specially designed greenhouse, in which both aquaculture and hydroponics circuits are installed. The fluid flows between the two parts of the plant are regulated by a patented system. Among others, one crucial component is a one-way valve which allows water to flow from the fish circuit towards the hydroponics if necessary, but not vice-versa. This is necessary to ensure the ideal growth conditions for both the plants and the fish.



Solar panels
deliver the power for all devices

A Aquaculture circuit
1. Fish rearing tank
2. Solid filter
3. Biofilter
4. Pump

B One-way valve
opens when water level in the storage tank is too low, allowing water to flow from the aquaculture to hydroponics system.

C Hydroponic circuit
1. Plants grow on rock wool mounted in troughs
2. Storage tank with pump for water and fertilizer
3. Cold trap to recover water vapor

Tomato fertilizer from fish wastewater

Animal welfare is an important issue in sustainable aquaculture. The tilapia live in tanks in which each cubic meter of water holds 50-70 kilogram of fish. This is a species-appropriate stocking density, which is optimal for this schooling fish. A lower stocking density would provoke turf wars, resulting in high stress levels. Stocking density that was too high would have the same negative effects.

Both fish and tomatoes need fresh, clean water in order to grow. Pumps provide water circulation through the system, and processed water from the fish tanks is used to irrigate the tomatoes. This water is purified in a two-step process: First, the water is passed through solid filters to extract particulate material. The water that leaves the filters contains ammonium, which is a metabolic product of the fish, excreted via the gills. The second purification stage of the recirculation cycle consists

A number of different plastic granules are used, depending on the type of the filter. Micro-organisms gain purchase on the small particles, and convert the ammonium in the fish wastewater into nitrate.

of a biofilter colonized by microorganisms. They live on “trickling filters”, which are bits of plastic with large surface areas. The bacteria convert the ammonium into nitrate through a process called nitrification. Nitrate is an excellent fertilizer, which accelerates the growth of the tomato plants.

The filtered, nitrate-rich water flows through the one-way valve from the fish to the tomatoes. This takes place automatically: water flows whenever it is necessary for the hydroponics. Another exchange between the tilapia and tomatoes takes place through the air: The fish exhale CO_2, which is taken up by the plants during photosynthesis, with oxygen returned to the air. And there is one more thing that the tomatoes deliver to the circulation system: evaporated water. The next chapter explains how it gets to the tilapia.

Soilless growth, thriving tomatoes

A thin layer of nutrient solution flows evenly around the roots of the tomato plants. The nutrients are recovered from the fish wastewater.

The tomatoes grow in a nutrient film technique (NFT), in which the plant roots grow in rock wool instead of soil. A thin, even layer of nutrient solution (the treated water of the fish cycle) flows through the plant troughs. The nutrient layer is absorbed directly by the plant's roots, and excess liquid is returned to the NFT holding tank. The tank provides an important service: if there is a nutrient deficiency at any point in the plant cycle, it can be corrected by readjusting the concentrations in the tank. The plant boxes are covered with black-and-white foil in order to prevent the growth of algae. This also prevents organic litter from the tomato plants from falling into the troughs. The soil-free conditions can also prevent pathogens from entering the system.

The plants extract nutrients from the water in which the roots grow. Excess water absorbed by the plants is released through the leaves into the surrounding air as water vapor – they "sweat" the purified water out. This water is collected via "cold traps" in the system's air conditioner. The gaseous water is condensed back into liquid, and can be redirected into a storage tank. If necessary, this clean water can be directly returned to the aquaculture facility. This reduces the daily need for freshwater to less than three percent of the total system volume.

Children's page

Fish and Tomato are best friends forever! They share everything they need to grow

Here's how it works: You take a couple of fish and a few tomato plants, and you let them share a nice warm greenhouse. Instead of growing in pots with soil, the tomatoes grow in long tubes within a layer of rock wool that the plants roots can cling to. Water constantly streams along the roots. The fish swim in a big tank next door.

Who eats what?

The fish get fishfood, but where do the tomato plants get the food that they need in order to grow thick and juicy? From the fish! In the Tomatofish building, a filter traps wastes from the tank's water. These wastes go through a biofilter that has special bacteria living in it. The bacteria change the ammonium the fish give off from their gills into nitrates. And that's the perfect fertilizer for tomatoes! The tomato plants make oxygen for the fish to breathe, by converting the carbon dioxide that the fish breathe out into tomatoes, roots, and leaves.

The whole building uses a cycle in which almost no water is lost. Even the water vapor that the plants sweat out gets caught, cooled down, and passed back into the fish tank. And that, ladies and gentlemen, is the Tomatofish!

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