Fish farming demonstration near Orlando, Florida.

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FUTURE FISH

The only way to meet the increasing demand for fish is through aquaculture. **Daniel Cressey** explores the challenges for fish farmers and what it means for dinner plates in 2030.

Sitting in an unremarkable family restaurant a short drive from his institute in Stirling, UK, Randolph Richards scans the menu's seafood offerings with an expert eye.

"The salmon is probably farmed in Orkney," he says, referring to an archipelago north of mainland Scotland. "The sea-bream — probably grown in Greece." Thus, the head of the University of Stirling's Institute of Aquaculture reveals a secret that most diners are blissfully unaware of: farmed fish are everywhere. Roughly every other morsel of fish passing through human lips was raised under human supervision.

> **"Even though the salmon look like fish they are almost more similar to pigs."**
> — Carlos Duarte

Right now, more than 50 million tonnes of glassy-eyed livestock are corralled in underwater cages and tanks, crowded, fed, sometimes dosed with antibiotics and ultimately culled and shipped up to half-way around the world to meet the ever-growing demand for fish. It's the world's fastest growing food sector.

From decadent fatty tuna belly savoured in the most expensive sushi joints to a workhorse frying fillet such as tilapia, farmed fish are becoming the norm rather than the exception, even if customers are unaware of the subtle change on their plates.

Back in the 1970s only 6% of the world's food fish came from aquaculture. By 2006, that proportion had risen to almost half, according to the biennial State of World Fisheries and Aquaculture report released last month by the Food and Agriculture Organization of the United Nations (FAO)[1].

And to keep up with world appetites, the fish-farming industry will have to continue this trend. The reason is simple, says Rohana Subasinghe, a senior fishery resources officer at the FAO. "We are not going to get adequate fish from the sea in the coming years."

Current projections suggest that by 2030 the world's population will have exceeded 8 billion people. Maintaining today's consumption rates, of around 17 kilograms per person per year would require an extra 29 million tonnes of fish. Meanwhile, around half of all fish stocks have been deemed "fully exploited" by the FAO, with those deemed "overexploited, depleted or recovering" now around 30%.

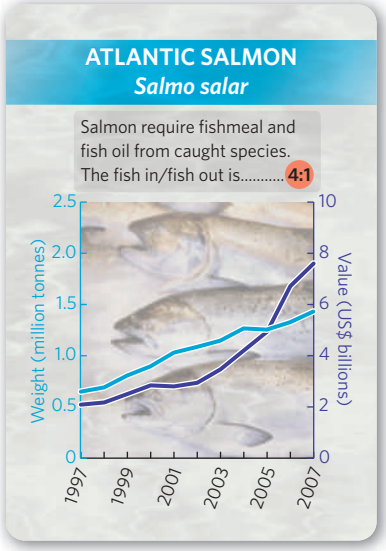
As a result, the fishing industry is casting about for anything even vaguely palatable. Although some consumers profess an aversion to farmed fish, claiming that they're bland, uninteresting or unnatural, many would choose a boring farm-raised salmon over fresh-caught pelagic delicacies such as jellyfish and krill.

"There's only so much wild stock out there," says Michael Rubino, manager of the aquaculture programme run by the National Oceanic and Atmospheric Administration in Silver Spring, Maryland. Most of the demand will have to be met by aquaculture, but what those future meals will look like depends very much on how much science can contribute to the trade. Predators, such as salmon and cod, are popular and command high prices at market. But their carnivorous diets rely on the same fish stocks that are under threat around the world. Tilapia — omnivorous cichlids — are fairly simple to raise. As one of the fastest growing aquaculture products, fish such as these may represent the future.

From paddies to pools

Aquaculture has been practised in China for many thousands of years. Carp were left to grow in ponds and rice paddies and later harvested. This passive, pastoral method, with little or no attempt to actively nurture the animals, is still practised widely. China produces 67% of the world's farmed seafood, much of it carp, and much of it through these generally low-tech methods.

Another short drive from his institute, and Richards is showing off a landmark piece of fish-farming's technological lurch forward. The Howietoun fish farm, built in the 1800s by a Victorian landowner, is still a commercial farm



K. SCHAFER/ZEFA/CORBIS

today. Brick-lined ponds, set on a gentle slope, teem with brown trout waiting for a few scoops of food and destined to stock lakes for sport fishing. When the fish in the uphill ponds reach a predetermined size, they are shuttled to the next via connecting channels.

The modern descendants of Howietoun have been attempting to drive up yields, along with profits, through the help of institutions such as the one Richards heads. Starting with veterinary science and progressively incorporating more and more disciplines, ranging from ecology to genetics, these research centres have helped to dramatically increase yields, but in doing so, they have created new problems.

The quaint, idyllic farm at Howietoun — where interference from otters and herons represent the extent of environmental conflict — is a far cry from modern industrial farms, which can involve miles of cages off the coast or huge collections of tanks on land.

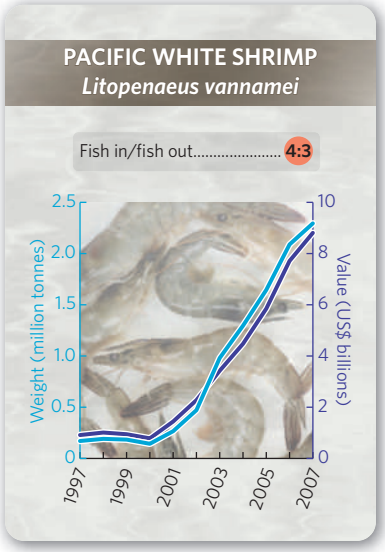
The most dramatic change in aquaculture has perhaps been the explosive growth in shrimp farming in southeast Asia. Encouraged by high demand and foreign investment, more than 109,000 hectares of mangrove swamp have been cleared for shrimp farming in the Philippines, for instance, since farming started in earnest in the 1970s. That's roughly two-thirds of the nation's area for these unique watersheds.

Furthermore, the nutrients added to many fish farms or produced as waste, particularly nitrogen and phosphorous, can trigger massive plant and algal blooms in surrounding waters. As the blooms die off, the bacteria taking part in the bonanza of decomposition suck the oxygen out of the system leaving it dead.

P. DALE/ALAMY

These environmental effects have caused many to oppose the idea of aquaculture, which the FAO says threatens future development in many regions. In response, farmers have been asking researchers to advise them on how much waste the surrounding sea can take. But farmed fish might not ever be a sustained replacement for caught fish: many farmed fish species rely on caught fish for food, in particular the ground-up solid fishmeals and liquid fish oil.

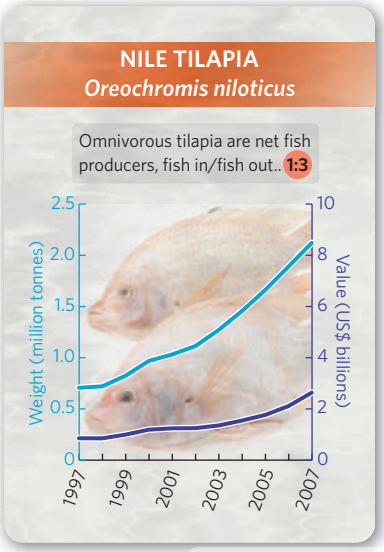
According to the FAO's statistics[2], aquaculture used 56% (3 million tonnes) of world fishmeal production in 2006 and 87% (800,000 tonnes) of fish oil production. Recent research[3] from Albert Tacon, of the Hawai'i Institute of Marine Biology in Kāne'ohe puts this even higher, at 3.7 million tonnes of meal and 840,000 tonnes of oil. Although the proportion of wild caught fish fed to farmed fish is small when set against the global total of capture fisheries, it is still a sticking point if the rationale for fish farming is to relieve pressure on overfished oceans.



M. SCHUTT/DPA/CORBIS

Strange chickens

Of the top seven most heavily farmed fish by weight, five are carp species, which generally require less food supplementation than other species. But carp is generally unfamiliar to Western diets. Number eight on the list has been quickly rising up the ranks and in the consciousness of Westerners: *Oreochromis niloticus*, the Nile tilapia. Tilapia — affectionately dubbed the aquatic chicken for their speedy and efficient growth — are to many a nearly perfect aquaculture species. The fish grow fast and are not choosy about where they live or what they eat. They occupy a low position on the food chain, so there's little opportunity for mercury to build up in their flesh — as is the case for some predatory species — and their flavour is sweet and inoffensive.



Although high-capacity tilapia farms once led to rapid breeding and disappointingly small adults, interbreeding species or using hormones can create single-sex broods, effectively taking the brakes off the population's rapid growth. Production boomed from next to nothing in the 1970s and 1980s to more than 2 million tonnes by 2007.

But much like the land-based avian namesake, these aquatic chickens are sneered at by many fish fans for their bland ubiquity. Westerners favour animals higher up the food chain: salmon, tuna and striped bass, among others. These animals have more rarefied tastes than the grubbing tilapia, and as they fetch a high price, farmers are keen to keep them on the menu.

To this end, some of the sea's carnivores have adopted a more vegetarian-like diet. In many farms, salmon, the predator farmed most heavily, have become accustomed to a diet of at least 25% soya bean, supplemented with fishmeal and fish oil at crucial times in their growth. "Even though they look like fish they are almost more similar to pigs," says Carlos Duarte of the Mediterranean Institute for Advanced Studies in Mallorca, Spain.

Other salmon may eat even more soya beans but such diets will reduce the levels of healthy omega-3 oils that have been a major selling point for salmon. Solutions in the pipeline include soya-bean crops that have been genetically modified to put these oils back in, and possibly even modifying the fish themselves. Traits such as fast maturation can be introduced through selective breeding. Other traits, such as disease resistance, will be harder to obtain without resorting to genetic modification, says Eric Hallerman, head of the Department of Fisheries and Wildlife Sciences at Virginia Tech in Blacksburg.

The US Food and Drug Administration (FDA) is considering approval of an Atlantic salmon that has been modified with the gene encoding for growth hormone from a Pacific Chinook salmon (*Oncorhynchus tshawytscha*). The addition of the gene could cut the time taken to reach market size by between a third and a half. The decision has been in the works for a long time[4], however, and there are no indications of a quick resolution. "I'd be really surprised if the FDA went forward before we give in our final report [on ecological risk assessment], which will be next September or October," says Hallerman, who is leading the work.

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And there are additional costs to consider. The big issue here, as with all genetically modified organisms, is preventing the fish escaping into the wild, where they may outcompete local fish, or where the modified genes could transfer to wild stocks.

To avoid this, Hallerman says that the modified salmon should only be grown onshore in tanks. At present, nearly all farmed salmon are grown in cages at sea, which puts onshore farmers at a disadvantage.

However, some in the fish-farming community say that this is the best place to farm fish. By using a series of graduated tanks — small tanks for hatchery up to large 'grow out' tanks — and recirculating water with pumps it is possible to grow dinner inside what is basically a warehouse. It also removes the variability that comes with being open to the ocean, allowing every stage of a fish's development to be carefully monitored and controlled, and helping to ensure a healthy fish for the market.

Although such technology costs money, some people using these systems are already making money, and any toughening up of regulations for outdoor aquaculture could make the recirculation systems even more attractive.

"Twenty years ago people would have told you we can't raise fish on land in recirculation systems. Ten years ago they would have said we can't raise them and make a dollar," says Hallerman. "People laughed at me 10 years ago when I said this, they didn't take it seriously. Now they're like 'show me how it works on a spreadsheet'."

But many people think the real opportunities lie in the deep ocean. Most fish farms are confined to the narrow strip of water near the coast, but advocates of 'open ocean' farming say that going farther out to sea is the way forwards. "On the one side there is unlimited potential," says James Diana, from the School of Natural Resources and Environment at the University of Michigan in Ann Arbor, "but it's also very expensive. It is a question of which of those two will win out."

Out to sea

Going offshore would remove many of the problems of near-shore farms: water quality is generally higher and there are fewer conflicts with recreational water users. But the open ocean can be fierce, and farms will need to be engineered much more heavily than they are now. Then there is the tricky problem of licensing. In the United States, for instance, there is no regulatory system for licensing fish farms in federal waters, so farms are limited to the 3 nautical miles (around 5.6 kilometres) off-shore that fall under state control.

"We currently do not have a regulatory framework for issuing permits for aquaculture in federal waters," says Rubino. "There are a few companies using offshore technologies in open ocean conditions in state waters, but none in offshore (federal) waters," he explains. "It's not suitable for all species and all locations but it's certainly something that many have recommended we look at going forward."

Although proponents think that being out at sea may cause less problems than being close to shore, some environmentalists have been fiercely opposed to open-ocean systems[5].

For Duarte, however, the opponents are missing the greater picture of food production. "We don't need to occupy a major fraction of the oceans to grow sufficient food. We have transformed 50% of the surface of the continents into crop lands and graze lands and yet we can probably [make] do with much less than 10% of the surface of the coastal ocean."

Consumer demand will probably push the technology as far as it can go, and in the West that means focusing on marine predators. But Duarte says that could change with the global food shortages. "Then the demand will be for mass production of food, and not so much for specific elements of quality."

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— Carlos Duarte

The farm at Howietoun will still probably be producing trout in 20 years. The restaurant nearby may still be serving farmed fish, be it genetically modified salmon, humble tilapia, tank-farmed tuna, or even carp.

If those who are partial to the taste of fish are lucky, an extra 30 million tonnes of fish will be on the market. Dinner won't be coming from the sea though, at least not in the traditional sense. The future is farmed. ■

Daniel Cressey writes for *Nature* from London.

1. FAO *The State of World Fisheries and Aquaculture 2008* (FAO, 2009).
2. FAO *Opportunities for Addressing the Challenges in Meeting the Rising Global Demand for Food Fish from Aquaculture* (FAO, 2008).
3. Tacon, A. & Metian, M. *Aquaculture* **285,** 146–158 (2008).
4. *Nature* **406,** 10–12 (2000).
5. *Nature* **431,** 502–504 (2004).