



Printing the Ocean's Bounty: How 3D Printing Is Reshaping Seafood

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ABSTRACT

Global seafood demand is rising even as fish stocks face growing pressure and a substantial share of every catch is discarded as skin, bones, shells, or trimmings. Three-dimensional (3D) food printing, once a novelty reserved for chocolate and pasta, is emerging as a practical answer to both problems at once. By turning surimi, fish gelatin, and other seafood pastes into printable "inks," researchers can build custom-shaped fillets, snacks, and soft foods for people with chewing or swallowing difficulties, all while diverting processing by-products that would otherwise become waste. Some laboratories are pushing further still, bioprinting cultured fish and shellfish tissue from living cells and offering a potential route to seafood produced without any fishing or farming at all. This article surveys how seafood 3D printing actually works, why fish pastes make unusually good printing materials, how food-industry waste is being valorized into desirable new products, and the technical, sensory, and regulatory hurdles that still stand between promising laboratory demonstrations and a genuine place on the supermarket shelf.

KEYWORDS

3D food printing, seafood, surimi, food waste valorization, bioprinting, printability, personalized nutrition

Introduction

Walk through any fish market, and you will see the paradox of modern seafood at a glance: gleaming fillets on ice, and beside them, heaps of heads, skins, shells, and trimmings whose final destination is the dustbin. The world eats more fish and shellfish than ever before, yet a striking share of every catch or harvest never reaches a plate in recognizable form. At the same time, an aging global population is creating millions of people who struggle to chew or swallow conventional food, and health-conscious consumers are asking for meals tailored to their own nutritional needs rather than one-size-fits-all portions.

Three-dimensional printing, long associated with prototyping plastic parts, has quietly moved into the kitchen. Food printers build edible objects layer by layer from soft, paste-like materials, much as an industrial printer builds a bracket from molten polymer. Over the past decade, food scientists have discovered that seafood, and surimi (a washed, minced fish paste) in particular, is an unusually good candidate for this technology. Its proteins form networks that behave like a natural printing ink, and the by-products of fish processing, skins, bones, and off-cuts, can be transformed into gelatins and pastes that would otherwise be discarded. Beyond conventional processing, some laboratories are going a step further, growing fish and shellfish cells directly into 3D-printed tissue that never touched the water. Together, these developments are turning 3D printing from a curiosity into a genuine tool for sustainability, customization, and food security in the seafood sector.

What Is 3D Food Printing, exactly?

Most food printers use a technique called extrusion-based printing, the same principle behind a cake-decorating piping bag, but guided by a computer. A soft, semi-solid material is loaded into a syringe or barrel, pushed through a narrow nozzle, and deposited in a pattern dictated by a digital 3D model. The machine builds the object one thin layer at a time, fusing each layer to the one below it until a complete shape emerges. Other approaches include inkjet printing, which sprays fine droplets of liquid ink, and binder jetting, which glues together layers of powder; but for seafood, extrusion is by far the dominant method because fish pastes are naturally thick and paste-like rather than liquid or powdery.

For a material to print well, it needs a delicate balance of properties. It must flow smoothly enough to be pushed through a nozzle without clogging, yet be firm enough that a freshly printed layer holds its shape and supports the weight of the layers printed on top of it. Food scientists call this balance "printability," and it depends on a material's rheology, essentially, how it flows and deforms under stress. Too runny, and the structure collapses into a puddle; too stiff, and the nozzle jams or the surface tears. Achieving this balance for a natural, variable material like fish flesh is one of the central challenges of the field.

Why Seafood? The Surimi Story

Surimi, the pale, minced, and repeatedly washed fish paste used to make familiar products like crab sticks and fish balls, turns out to be almost tailor-made for extrusion printing. When surimi is heated, its myofibrillar proteins unfold and re-link into a dense gel network, giving printed structures

their characteristic chewy, cohesive bite. Because surimi can be produced from a wide range of underused or lower-value fish species, printing it into elaborate shapes offers processors a way to raise the value of a commodity ingredient rather than selling it as an anonymous block.

A 2024 study on shrimp surimi illustrates just how sensitive the printing process is to its physical settings. Researchers systematically varied nozzle diameter, print height, print speed, and infill density to find the combination that produced the most accurate and stable structures, and found that a narrower nozzle paired with a slightly larger gap between the nozzle and the print bed allowed successive layers to fuse properly, while printing too quickly caused uneven extrusion and broken filaments. The choice of cooking method mattered just as much as the printing parameters themselves: steaming, boiling, and deep-frying caused noticeably more shape distortion than oven-baking or microwaving, and panels of tasters consistently rated the oven-baked products highest, since microwaving altered both color and texture in ways evaluators disliked (Pan et al., 2024). The lesson is a useful one for the whole field: a recipe that prints beautifully can still fall apart, quite literally, if the wrong cooking method is applied afterward.

A broader review of surimi printing research reinforces this point and extends it. Surimi alone is rarely sufficient; producers typically add structural enhancers such as salt, transglutaminase (an enzyme that stitches proteins together), or plant-derived biopolymers to strengthen the gel network and improve printing fidelity, and the technology appeals to specific groups:

children who enjoy novel shapes, elderly consumers with reduced chewing ability, and people managing dysphagia, a swallowing disorder that makes conventional textured food difficult or dangerous to eat (Diao et al., 2025). Rather than serving as a novelty act, in other words, 3D-printed surimi is increasingly being framed as a tool for inclusive nutrition, letting people who cannot manage a regular fillet still enjoy something that looks and tastes like one.

Turning Fish Waste into Printable Wonder

Perhaps the most compelling argument for seafood 3D printing is not novelty but circularity. Fish processing generates enormous volumes of skin, bones, heads, and trimmings, material that is nutritionally valuable but commercially awkward. Printing offers a way to reshape these by-products into something a consumer would actually choose to buy.

Salmon skin is a case in point. Chile, one of the world's largest salmon producers, processes hundreds of thousands of tons of salmon annually, and only a little over half of that volume is sold for direct human consumption, leaving skins and other by-products as an underused resource. A 2022 study extracted gelatin from salmon skin and tested it as a 3D printing ink at several concentrations. The researchers found that an 8% gelatin gel struck the right balance of flow and firmness: it extruded smoothly through the nozzle, yet the printed structures held their designed dimensions over time without slumping or spreading (Carvajal-Mena et al., 2022). In practical terms, a material once destined for rendering or disposal became a

food-grade printing medium capable of producing precisely shaped, stable products. Cod by-products have received similar attention. A study from Iceland used low-field nuclear magnetic resonance (LF-NMR), a technique that tracks how water molecules are distributed and move within a food, to monitor the quality of 3D-printed surimi made from cod trimmings. The researchers compared two processing routes: a modern pH-shift method, which adjusts acidity to isolate proteins, against conventional washing. They discovered that raising the salt content to 3% had a stabilizing effect on the printed surimi in both cases, and that printing with the freshest possible raw material gave the most consistent results, since longer cold storage before printing shifted how water was bound within the protein structure (Gudjónsdóttir et al., 2019). Studies like this matter because they move seafood printing beyond "can we make a shape" and toward "can we guarantee a safe, consistent, storable product," which is the real test for any commercial food technology. This waste-to-value logic extends well beyond seafood specifically. Reviews of food-industry waste valorization through 3D printing point out that shellfish shells, fruit peels, and vegetable trimmings can all be converted into printable pastes, fiber-enriched snacks, or even biodegradable packaging, with some case studies reporting meaningful reductions in waste-disposal costs and material losses when manufacturers adopt these approaches. Applying the same thinking specifically to seafood by-products, rich in collagen, minerals, and unsaturated fats, gives processors a path to squeeze considerably

more value out of every fish that comes off the boat.

Growing Fish Without the Ocean:

Bioprinting Cultured Seafood

While surimi printing reshapes existing fish tissue, an even more ambitious branch of the field is trying to grow seafood tissue from scratch, without a single fish being caught. Cultured, or "cell-based," seafood starts with cells taken from a fish or shellfish, which are then multiplied in a nutrient-rich growth medium before being assembled into a food product. 3D bioprinting offers a way to arrange these growing cells into structures that mimic the layered, fibrous architecture of a real fillet, rather than the shapeless mass produced by simple cell culture alone.

A 2024 narrative review of bioprinting for cultured meat and seafood describes this as a genuinely interdisciplinary undertaking, combining cell biology, materials science, and mechanical engineering. Researchers must select suitable cell types, formulate "bioinks" that keep cells alive and functional during and after printing, and design bioreactors that can support cell growth at a scale large enough to be commercially meaningful. The review frames the approach as a potential answer to the environmental and social costs of ever-expanding wild capture fisheries and industrial aquaculture, since it could, in principle, decouple seafood production from ocean ecosystems entirely, while candidly noting that optimizing serum-free growth media, scaling up bioreactor design, and addressing consumer trust and regulatory approval all remain significant open problems before cultured, bioprinted seafood becomes anything more than a laboratory demonstration (Gurel et al., 2024).

It is worth being clear-eyed about where this technology currently stands. Bioprinted seafood is not yet on any menu, and the cost of producing even small quantities of cultured tissue remains far higher than conventional fish. But the underlying logic, that texture and structure can be engineered layer by layer rather than grown organically inside a living animal, connects this cutting-edge research directly back to the more down-to-earth surimi printing described earlier. Both rely on the same core insight: that food architecture can be designed digitally and built physically, one thin layer at a time.

Beyond the Fillet: Personalization and Special Diets

One of the quieter but more significant promises of food printing is customization. Because a printer builds whatever shape a digital file describes, portion size, geometry, and even internal structure can be adjusted for an individual person rather than mass-produced identically for everyone. For dysphagia patients, whose swallowing difficulties are usually managed by pureeing food into unappetizing, texture-modified meals, printing offers a way to recreate the visual appeal of a normal dish, a recognizable fish shape, say, while still meeting strict internationally recognized texture standards for safe swallowing. Reviews of 3D-printed foods for this population note that adding hydrocolloids such as gums, starches, or gelatin during preparation can make otherwise unprintable ingredients printable, broadening the range of nutritious foods, including fish and other proteins, that can be safely offered to patients who might otherwise be limited to bland, unrecognizable purees.

The same underlying flexibility supports personalized nutrition more broadly. A printer can, in principle, adjust the mineral, protein, or fiber content of a printed product to match an individual's dietary needs, medical restrictions, or even athletic goals, moving food production a step closer to a "just for me" model rather than a one-size-fits-all supermarket shelf. Recent reviews of 3D food printing highlight this personalization potential alongside its role in reducing waste, framing the technology as part of a broader shift toward more digital, data-driven, and sustainable food systems (Bishta et al., 2026).

The Challenges That Remain

For all its promise, seafood 3D printing faces real obstacles before it moves from research laboratories to everyday kitchens and factories. The most fundamental is printability itself: fish tissue is a naturally variable, biological material, and its rheological behavior changes with species, freshness, fat content, and even the time of year it was caught. Formulating a consistent, reliable printing ink from such variable raw material, without leaning too heavily on additives that consumers may view with suspicion, remains an active area of research.

Sensory quality is another hurdle. A shape that prints perfectly is worthless if it does not taste, smell, or feel like food people want to eat. The shrimp surimi study discussed earlier is a reminder that even a well-optimized print can be ruined by an inappropriate cooking step, and that consumer taste panels, not just engineering metrics, must guide any final product design. Cost and throughput present a further barrier: current food printers are slow compared with conventional processing lines, and scaling from a laboratory prototype

capable of producing a single object over several minutes to an industrial process capable of feeding a supermarket supply chain is a substantial engineering leap.

Regulatory and safety questions loom particularly large for the more novel branches of the technology. Bioprinted, cell-based seafood in particular will need to clear food-safety approval processes in most countries before it can be sold, a process that is still being defined for cultured foods generally. Even for more conventional printed surimi products, ensuring consistent microbial safety, especially when raw fish pastes are stored, reformulated, and reheated through multiple processing steps, requires the kind of careful, ongoing quality-monitoring work described in the cod by-products research discussed earlier.

Looking Ahead

Despite these hurdles, the trajectory of the field points toward broader adoption rather than a passing niche. Researchers are already exploring extensions of standard 3D printing, sometimes described as 4D or 5D printing, in which printed foods are designed to change color, shape, or texture in response to cooking, moisture, or time, opening possibilities for interactive or self-transforming seafood products. Machine learning and computer-aided design tools are also beginning to appear in food-printing research, helping scientists predict which ink formulations and printing parameters will succeed without the trial-and-error of physical testing every combination.

What makes seafood particularly interesting within this wider food-printing movement is the convergence of two pressures that are unlikely to ease any time soon: rising global

demand for protein-rich, ocean-derived food, and growing awareness that a large share of every catch is currently wasted. Printing technology will not, by itself, solve either problem. But by turning trimmings into gourmet-shaped products, by making swallowing-safe meals that still look like a proper meal, and by opening a long-term path toward tissue-cultured seafood grown without a hook or a net, 3D printing gives the seafood industry a genuinely new set of tools for tackling both challenges at once.

Conclusion

Three-dimensional printing has moved seafood science well beyond its origins as a gimmick for novelty-shaped chocolates. Surimi and fish gelatin have proven to be unusually well-suited printing materials, and careful control of printing parameters and post-processing, as shown in shrimp surimi and cod by-product research, can turn them into stable, appealing, and nutritious products. By-products once considered waste, salmon skin among them, are being valorized into food-grade printing inks, while bioprinting research is laying the groundwork for seafood grown entirely outside the ocean. Challenges around consistency, taste, cost, and regulation remain substantial, but the direction of travel is clear: 3D printing is steadily becoming a practical, sustainability-minded tool for the future of seafood, not merely a laboratory curiosity.

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