Chapter 3
Engineering a Solution for Managing Fish Waste

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Fish and humans have a long-standing predator-prey relationship. Fish have been, and remain, an important component of human diet, and fisheries are central to many coastal communities' economies. According to Serge Garcia (2005), globally about 17% of animal protein is derived from fisheries, with greater percentages in coastal communities. Garcia states, "The most considerable and substantial contribution of fisheries worldwide is the supply of highly nutritious animal protein for human consumption and the employment and income generation in often-remote coastal areas" (n.p.). Well-managed sports fisheries also can contribute appreciably to an economy through recreation and tourism.

The unusual life cycle of migrating from freshwater to saltwater and back again is called anadromy, and fish that exhibit this pattern are anadromous (Montgomery 2003). Both in transit to spawning waters and in death, anadromous fish contribute important marine-derived nutrients to freshwater ecosystems. American Rivers notes: "Food resources for almost all kinds of animals are variable in space and time, but the anadromous fish system is an extreme case in which prey is temporarily very abundant, spatially constrained, relatively easy to capture, and more or less predictable" (n.p.). Mary Wilson and Karl Halupka (1995) also note: "… Wildlife species capitalize on available concentrations of anadromous fish and may change their distribution and even breeding biology in response to the abundance of these fish" (p. 493).

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When Alaskans think of anadromous fish, a salmon steak or a fillet sitting on our dinner plate probably come to mind. Those of us who live near an abundant wild salmon population know the effort it takes to get these fish from the ocean or stream to the dining room table, and we know also how much of each fish goes unused in the process. Once cleaned and the nutritious flesh removed, the unused remains must be disposed of. There are various methods for doing so, but some of these methods can be considered polluting, while others can cause unintended consequences, as discussed below.

3.1 Fish Waste Issues

Salmon anglers typically retain fillets from their catch, which leaves the carcass as something that an angler needs to dispose of. While Alaska Natives conventionally use the entire fish, most anglers consider the carcass to be "waste". Moreover, the salmon carcass is either disposed of onsite, such as in the stream or ocean, or the fish is packed out whole and the carcass is disposed of later with other waste, such as one's home garbage. For anadromous fish, the volume of fish waste produced over a period of time is much larger than a non-anadromous species. This is primarily because many Alaskans catch enough salmon to sustain them through the year, and anadromous species have a defined run period, during which large quantities are present in a river over a short, finite period of time.

This fish waste, if not disposed of properly, can create a myriad of issues. According to Oasis Environmental in the 2012 ADEC Fish Waste Management Plan: Kenai Personal Use Dipnet Fishery:

> A large volume of fish waste disposed of in a particular location can create accumulations of waste sludge and whole fish parts, cause the generation of toxic hydrogen sulfide gas, if discharged to surface water could cause dissolved oxygen concentration to decrease below state water quality standards (WQS), increase the concentrations of scavengers, and create noxious conditions caused by odors, bacteria and waste decomposition (p. 1).

Not only can fish waste create water quality issues, smell, and attract pests, but it also can create an aesthetic concern for visitors to Alaska. This is important, due to the increasing emphasis on ecotourism for the state: ecotourists are a significant part of the economic future in Alaska.

Whether fish are caught commercially or recreationally, waste results. Commercially caught fish waste is the responsibility of the business producing it, but recreationally caught fish waste often ends up as the responsibility of the fishing area's land management entity (more specific to freshwater fisheries), and fish waste management is imperative.

3.2 Fish Waste Management

In coastal and riverine environments where fishing is popular clutter, the most common annoyances associated with fish waste are aesthetics and odor. However, in southcentral Alaska on the Kenai Peninsula, specifically the Russian River recreational fishery, how fish waste looks and smells to them may be the least of anglers' worries. Most fish carcasses are disposed of in shallow waters or slow-moving areas and end up on river banks. These carcasses attract scavenging wildlife such as gulls and bald eagles, but also resident brown bears.

Various fish waste disposal and management options for different sites have been considered in the past. Let's explore these next.

3.2.1 Ocean Disposal

Most fisheries are based on salmon that are caught commercially in the ocean. Commercial fishing vessels catch the fish and either process them onboard or transport them to a cannery facility on land. Once the parts of the fish deemed useful have been processed, the remainder of the carcass must be disposed of. Canneries often grind the fish waste into small pieces of a mandated size, then transport and dump the sludge at a location offshore where most of it sinks and collects on the ocean floor.

As this sludge decays, the bacteria facilitating the decay consume oxygen. These offshore sludge dumps often result in a locally significant oxygen sink: the dissolved oxygen concentrations in the water become too low for some ocean life to survive. Canneries and others using this disposal method are required by the Environmental Protection Agency (EPA) and other permitting agencies to monitor these areas closely.

River-based fisheries also can use ocean disposal; however, this method involves greater transportation costs and can still contribute to environmental problems.

3.2.2 Landfill

For smaller quantities, fish remains can be deposited with the rest of human-generated trash in municipal landfills. Larger quantities of fish waste create problems. "In many countries, solid waste is recycled into fish meal plants or treated along with the municipal waste, whereas liquid waste is disposed of through the municipal sewage system or directly into a waterbody" (FAO Fisheries and Aquatics n.d.). On the Kenai Peninsula of Alaska, the local landfill limits the amount of fish waste accepted, and requires notification and approval of larger quantities for dumping, so when the waste arrives, it can be covered immediately.

3.2.3 Composting and Fertilizer

A green, productive garden can result from beneficial use of fish waste. In 1989, a New York state law was passed that restricted the disposal of fish waste, with a few exceptions. These restrictions helped lead to the discovery, by researchers at Cornell University and the New York Grant Extension Program, that a mixture of fish parts and peat moss could create an effective compost for gardening (Environmental Protection Agency [EPA] 2012).

3.2.4 In-River Disposal

For riverine fisheries, a common method for disposing of fish waste is to return the carcasses to the river from where they came. This method resembles what happens naturally: as fish die, their marine-derived nutrients are left near the site of death for the surrounding vegetation and animals to use. This disposal method can include tossing the entire carcass into the water, or chopping/grinding the waste before disposal. The success of this disposal method depends greatly on several factors: the amount of fish waste being generated, the popularity of the fishery, the size of the waterbody (i.e., flow rate), the water velocity, and the size of the fish-waste particles.

I want to focus more specifically on the Russian River near Cooper Landing on the Kenai Peninsula of Alaska (Fig. 3.1), and the sockeye salmon runs that occur twice each summer. Despite this focus, however, there are other streams that have similar issues throughout the Pacific Northwest, and what I will discuss has greater implications nationally.

The fish-waste issues on the Russian River are fairly unique in the fact that many of the issues manifest at one specific location. The Russian River is smaller than the Kenai River, and has slower velocities; the sockeye salmon runs in the Russian River are abundant, and the fishery attracts as many as 150,000 anglers (Fig. 3.2) annually (United States Forest Service [USFS], United States Fish and Wildlife Service [USFWS] and Alaska Department of Fish and Game [ADF&G] 2013). In the past, ADF&G has stated that the first run, occurring sometime before June 15, averages about 27,000 fish, whereas the later run, which occurs near mid-July, averages around 61,000 fish (ADF&G 2006). The small size of the stream, relative to the size of the fishery, creates an overwhelming large amount of fish waste. As with other riverine fisheries, the quantity of fish waste attracts wildlife. However,

Fig. 3.1 Kenai and Russian River Confluence Area (GoogleEarth 2011)

Fig. 3.2 Anglers in the Kenai River near the Russian River Confluence (© Alexandra West)

the Russian River also happens to be in an area that is home to a large population of brown bears that visit the location for the same reason anglers do—to catch salmon.

During the summer of 2008, nine brown bears were killed on the Russian River (Campbell 2009). These bears either became aggressive towards humans or threatened people or their property along the river. This is unfortunate, for the Russian River two sockeye salmon runs benefit both humans and bears. While bears and humans share the food source, humans leave the remains of their catch—and this, in turn, attracts unwanted attention from the bears.

Anglers have been asked to dispose of their waste properly. With any fish management procedure, public education is imperative. The area's management organizations, including the U.S. Fish and Wildlife Service (USWFS), the U.S. Forest Service (USFS), and the ADF&G have tried various methods of fish waste disposal. These agencies have suggested refraining from in-river disposal by educating anglers to either pack the fish out whole and clean it elsewhere (disposal of the fish waste likely using landfill disposal), or chop the carcass into many small pieces and throw them into fast-moving water. Over the years, these agencies have placed fillet tables in strategic locations to encourage anglers to dispose the fish waste in the faster-moving water; they have also placed hand grinders here and there to encourage anglers to grind the fish carcasses into small pieces before disposal. Unfortunately, area management has reported that these methods have not been successful: users do not want to exert the extra effort to grind the carcasses, and they do not usually chop the carcass into small enough pieces. As a result, the pieces can concentrate in eddies or areas where the water flows slowly, and thus, still collect on the riverbanks.

3.3 Hydro-powered Fish Carcass Disposal System

To retain the marine nutrients in the riverine ecosystem and to prevent large, odorous pieces of fish from collecting on the riverbanks and attracting wildlife, small pieces of the fish carcass must be dispersed into fast-moving water. For this method to be effective, the disposal process must be near effortless for the anglers: history has shown that anglers are unlikely to grind their waste up themselves. A grinder still seems to be the solution—but a power source other than human muscle may need to be considered.

I can't say when I first became intrigued with fish and engineering, but growing up in a wildlife- and science-minded family helped. Furthermore, in elementary school, my 5th and 6th grade classes participated in an "Adopt a Stream" program. We would often walk, as a class, down to Slikok Creek, near our school, and spend time with a biologist collecting aquatic insects, setting fish traps to catch and identify juvenile salmon, and taking water quality measurements—all of which were used to collect ongoing information on the health of the stream. Additionally, I was lucky enough to help care for our ADF&G-sponsored "Salmon in the Classroom", which involved raising baby salmon from eggs to fry, in our school, before releasing them. Learning about the importance of our salmon, watersheds, and ecosystem at a young age helped me later pair my growing passion with my higher-level STEM education in engineering to invent the hydro-powered fish-carcass disposal system.

As an undergraduate civil engineering student at the University of Alaska Anchorage (UAA), I was tasked with selecting a project I was passionate about that pertained to engineering. I had been aware of the issues along the Russian River for years because it was near where I had grown up and my father was involved with managing the area. As a civil engineer, I did not go into detail designing a grinding system—that task could be left to a commercial grinding company or a mechanical engineer! But I could investigate methods for powering the device. I focused on hydrology and hydraulics at UAA, and thought, how might one power something in or near a river? With a problem identified and a question asked, I began designing a conceptual hydro-powered fish-carcass disposal system. UAA patented the device in 2014 under U.S. Patent 8,833,682 B2. In 2015, three senior undergraduate civil engineering students (Jennifer Baker, Nathan Harris, and Brandi Opsahl) contributed to a more complete design for their capstone course at UAA.

3.3.1 Design

The designed hydro-powered fish-carcass disposal system harnesses the energy of flowing water using an undershot paddlewheel. The paddlewheel rotates, and these rotations either directly turn the grinder through a gearing system, or the paddlewheel connects to a generator that would then power a commercial-style electric grinder. The entire system is mounted on pontoons in the river, connected by cables and a slide from the bank. The slide allows anglers to fillet their catch on a cleaning table, and toss the waste on the slide, which feeds into the grinder. Figure 3.3 shows the 2015 plan drawing of the system.

3.3.2 Location

As previously mentioned, the Russian River is the location of concern. Part of this popular fishing spot includes the confluence of the Kenai River with the Russian River. The sockeye salmon fight upstream from the ocean, approximately 74 river miles from the Kenai River's mouth at Cook Inlet to the Russian River confluence,

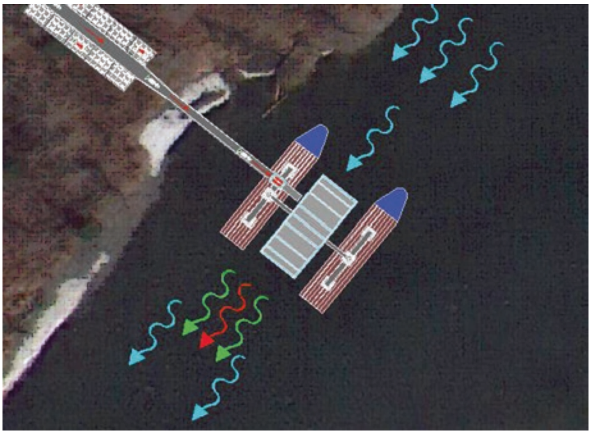

Fig. 3.3 Conceptual layout of fish cleaning tables and the paddlewheel grinding system (Baker et al. 2015)

Fig. 3.4 Potential location of the hydro-powered grinding device on the Kenai River (©Alexandra West)

and then into and up the Russian River to spawn. Anglers fish along the confluence as well, but the Kenai River is much wider and deeper, which reduces anglers' ability to wade in the water, but also makes it easier to dispose of fish waste into faster currents.

The Russian River itself does not have water velocities great enough to power a hydrokinetic device capable of powering a grinder large enough to handle fish waste, but the Kenai River does. The fish-table/grinding device (or devices) could be deployed in the Kenai River, at a location accessible to anglers leaving the Russian River area. The proposed location is adjacent to parking lots, a boat launch, and the renowned Russian River Ferry. The Russian River Ferry is a privately owned business that charters anglers across the Kenai River, from the highway side to the Russian River and the confluence.

The preferred location for a grinder device is across the Kenai River from where most of the fishing occurs (Fig. 3.4). At that location, water depths are greater, there is less of a navigability hazard to rafters and drift boaters, and the area is still accessible to anglers after they leave their fishing site. The location also affords a significant educational aspect: area management would probably need to encourage anglers to either pack out their catch, or get the fish waste to the grinder area.

3.3.3 Size

The size of the device will depend on the stream's water velocity. Undershot paddlewheels are not very efficient, but they work well in lower-velocity conditions. They are also relatively cheap and fairly straightforward to construct. The device's paddles are sized proportionally to the average speed of the river during the period of use, and they float off the bank at a specific distance where velocity is maximized (without being in the main part of the channel and causing a hazard to boaters). Once the paddles have been sized, the rest of the device (frame and pontoons) can be sized to ensure it stays erect and afloat.

3.3.4 Grinder

Due to environmental concerns and permitting regulations, the device must be able to grind fish waste to particles that are about 0.5 inches in any direction. A non-motorized grinder could be designed to do this task, or a commercial grinder, such as those used at canneries, would be hooked up to a generator. Our research indicates that a grinder capable of grinding fish bones (specifically skulls) into small enough pieces would need approximately 5 horsepower. The JWC Environmental 3-SHRED grinder is an example of a commercial grinder that has been used in canneries and that has met permitting discharge regulations.

3.3.5 Environmental Concerns

Although the "Stop, Chop, and Throw" process has been suggested and used by professionals for many years, discharging organic material can raise some important environmental questions. Oxygen is needed to decompose organic materials, so discharging a large quantity of fish waste in one location, even if the particles are small, could accelerate oxygen consumption. This could create a significant dissolved oxygen sag downstream of the device, which in turn could harm salmon, other fish, and macroinvertebrates in the river.

Another concern is particle transport. Small pieces of fish waste might flocculate, fall to the streambed, and create a massive "slime" downstream of the device. Initial calculations based on a conservative assumed use of the device during the peak fishing season have shown that the small fish waste particles should easily be transported and dispersed downstream, so dissolved oxygen probably would not become an issue (Baker et al. 2015).

3.3.6 Health and Safety

As with any highly used area, public health and safety must be considered. The device would need to be monitored to ensure it is not misused or abused, and examined daily (according to the Alaska Department of Environmental Conservation) to ensure that it is functioning properly and that discharges meet the aforementioned regulations. The grinder itself would be positioned out on the device, encased in a hopper so that no sharp components would be exposed. The grinder also would be kept clean by pumping water frequently down the slide and through the blades. Pumps could be attached to the device and powered through a generator, or water could be obtained through a water retrieval system connected to the paddlewheel, similar to waterwheels, or norias, used throughout history for water retrieval and irrigation.

3.4 A Solution to Fish Waste Management

Whatever mess results from fish waste—odor, aesthetics, or pests such as gulls, or bears—it must be managed appropriately. Not all locations will be able to benefit from a hydro-powered disposal system, but other waste-handling methods, such as composting and those discussed earlier, need to be considered holistically. Ultimately this chapter provides a powerful idea for the ingenuity of STEM students as they explore the role of animals in relation to science education and the ways that engineering is now inseparable from it.

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