Addressing Invasive Carp and Boosting Economic Development through Market-based Solutions

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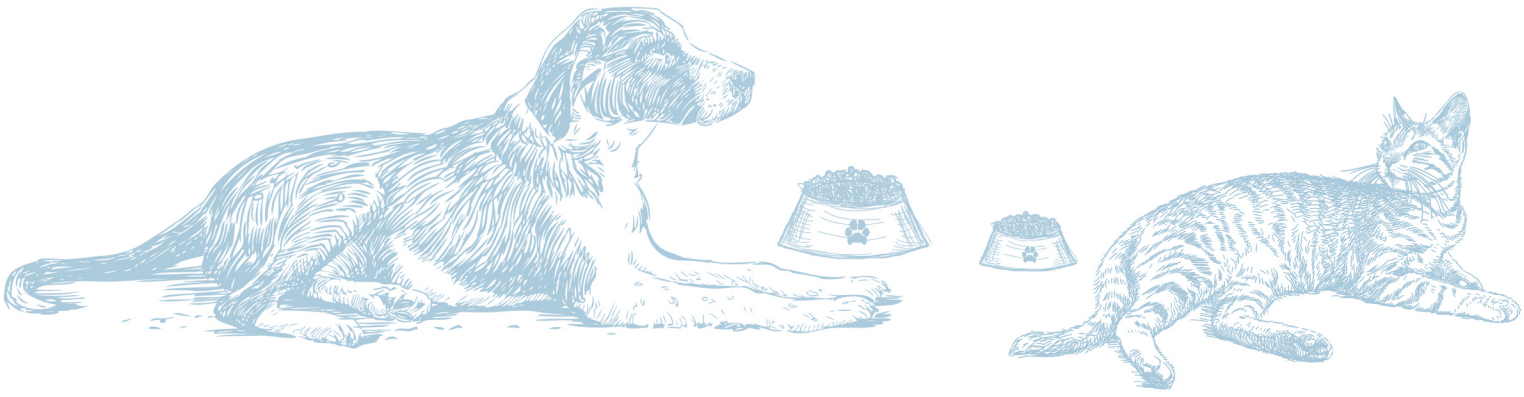
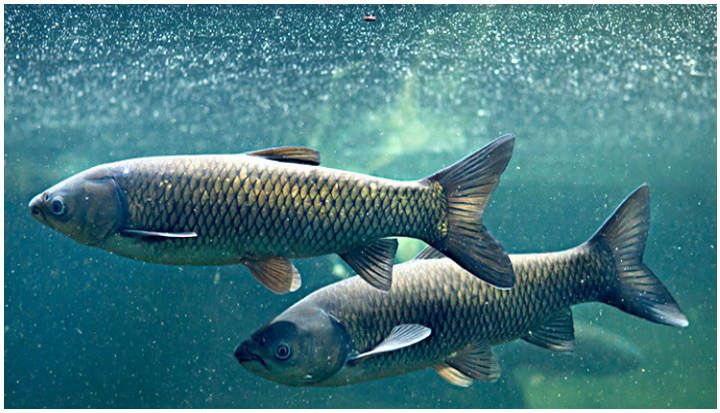
Disclosure

WWF Impact, WWF's impact investing arm, is invested in Chippin, a pet food company working with carp. Further details are available in "Phase II and Next Steps".



Clockwise from top left: Silver Carp *(Hypophthalmichthys molitrix), © slowmotiongli / iStock*; Grass Carp *(Ctenopharyngodon idella), © wrangel / iStock;* Bighead Carp *(Hypophthalmichthys nobilis), © M. Spencer Green / AP;* Black Carp *(Mylopharyngodon piceus), © blickwinkel / Alamy*

Executive Summary

Four species of carp, including silver, grass, black, and bighead carp, were intentionally introduced to the US in the 1970s to clean aquaculture retention ponds, but quickly escaped into the Mississippi River. As an invasive species with no natural predators in the river, they proliferated, causing environmental and economic damage. Today, while precise quantification is difficult, some estimates suggest that carp may constitute up to 95% of biomass in parts of the Mississippi and Illinois Rivers.

As prolific breeders with a very fast growth rate and that are highly adaptable to new and changing conditions, carp have spread quickly, causing both direct and indirect harm. They outcompete native fish for food, thereby breaking the larger food web, and decimate water quality. They also impose economic harm. By decreasing native sport fish populations as well as silver carp's jumping behavior, carp disrupt sport fishing – a $10 billion industry in the Midwest alone. North America has spent more than $26 billion annually since 2010 to combat invasive species, including carp, but with little success.

Carp are a highly nutritious fish with a very mild flavor but have seen limited market use in the United States. They are extremely bony, making it very difficult to cleanly filet the fish and thereby limiting human demand. There are nascent efforts in this area, as well as in pet food, but pet food companies have been hesitant to invest in a supply chain when eradication may be the ultimate goal and without a better understanding of the potential environmental benefits. Without market demand, there has been limited processing and so inconsistent supply, leading to a vicious cycle. However, the pet food market is a significant and growing industry facing shifting supply chains that may provide an opening.

Traditionally, the pet food industry has made use of byproducts from human consumption, but shifts are occurring due to both supply and demand changes. On the supply side, growth in pet food shows signs of outpacing the availability of human byproducts. This potential supply chain bottleneck is happening while larger shifts are at play across the industry. There is an increasing focus on the humanization of pets and an associated expansion in fresh and frozen high-end pet food that makes use of human grade ingredients. However, despite this change, plant-based ingredients still make up the single largest input

into pet food. Soy, one traditional plant protein alternative to animal meat, is facing increased demand from alternative fuels and may soon be cost prohibitive to pet food companies. Carp could provide a new ingredient that limits direct sourcing of animal proteins that aren't byproducts while also limiting the deforestation that could occur if further soy acreage needs to be planted to meet expanding demand.

Sourcing carp also has the potential to bring environmental benefits to the Mississippi River Basin. While eradication is unlikely to occur at any harvest level, even a low-to-moderate level of harvest could help limit further spread of carp, especially into the Great Lakes, suppress density of local populations (at more moderate levels of harvest), restore natural ecosystem services, and improve biodiversity. While additional research is needed to better quantify the exact benefits, it is clear that sustained market demand could bring significant improvements to the US riverway system.

A robust carp supply chain will not be possible, however, without supporting fishers. Like many physically demanding jobs at the beginning of lengthy supply chains, fishers have faced declining numbers in recent years, especially as it has become increasingly difficult for commercial fishers to earn a living wage. There have been, however, some successful efforts to support fishers, including community supported fisheries, co-ops, quotas, and the integration of sustainability and traceability. There are also learnings that can be gleaned from other groups of workers similarly situated at the start of lengthy supply chains, such as hub and spoke models, vertical integration funded through creative business models, pooled funds, and new technologies that can be tied to higher revenues. As a carp supply chain is built, it will be imperative to make use of these or similar models to ensure long-lasting supply and equity in the supply chain.

While there has been significant progress made in learning about the potential of market-based opportunities for carp, it is imperative to transition that research into action while also laying the groundwork for replicability and scalability to other invasive species. Building robust market demand for carp provides a chance to address environmental harm to the broader Mississippi River Basin, boost economic development in the Midwest, and even improve the environmental footprint of pet food supply chains. However, it also provides a chance to gain valuable feedback and to serve as a proof-of-concept of an additional tool to fight invasive species. While markets-based approaches will not be the right solution for all invasives, if successful, this project could become a new model of another option and spur further research, learnings, and action worldwide.

Silver carp harvest in Kentucky. Due to their sheer numbers, they are relatively easy to catch in large numbers fairly quickly. *© Nathan Eftink - KDFWR*

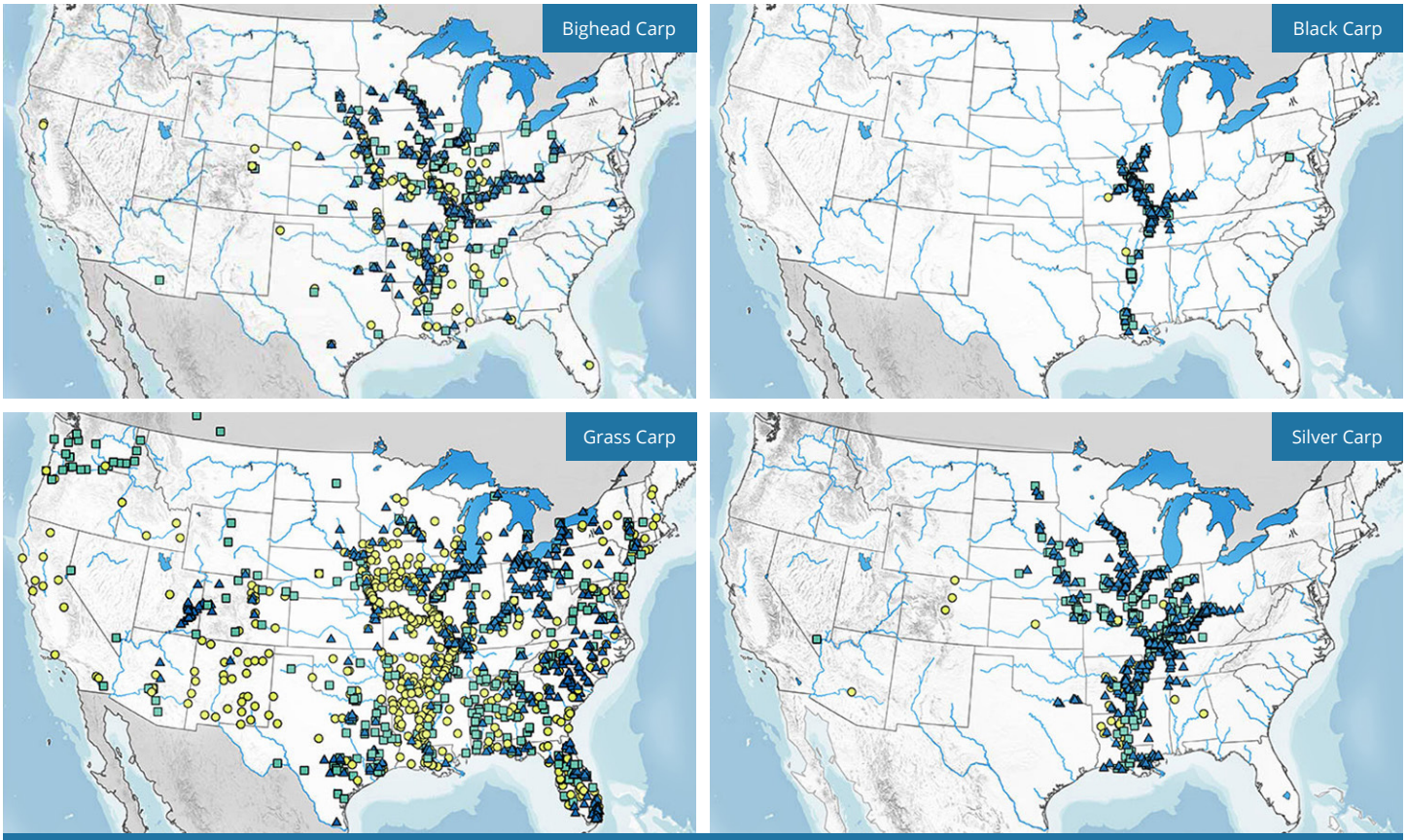


Figure 1: Invasive carp spread in US riverways. Year of observation: ● 1968-1992, ■ 1993-2007, △ 2008-2021

© U.S. Geological Nonindigenous Aquatic Survey, Species Database, December 2021

Background

Four species of carp, including bighead, black, grass, and silver carp, were intentionally introduced to the US in the 1970s to clean aquaculture retention ponds, but quickly escaped into the Mississippi River. As an invasive species with no natural predators in the river, they proliferated, causing environmental and economic damage.

Today, while precise quantification is difficult, some estimates suggest that carp may constitute up to 95% of biomass in parts of the Mississippi and Illinois Rivers.[1] Since 2010, North America has spent more than $26 billion annually to combat invasive species, including carp, but with little success.[2] The funds have primarily gone towards physical barriers to prevent spread and most efforts today focus on preventing carp from entering the Great Lakes.

Environmental and Economic Impact

Carp have wrought environmental damage across the Mississippi River Basin. They are prolific breeders with a very fast growth rate and are highly adaptable to changing and new conditions. They are also largely planktivorous fish, meaning plankton makes up a significant portion of their diet. Without a natural predator they have continued to reproduce abundantly, bringing harm both directly and indirectly across the river ecosystem.

Carp directly outcompete planktivorous native fish, such as paddlefish, gizzard shah, bigmouth buffalo, and emerald shiner. They simply dominate food sources through sheer proliferation. Many other fish species are planktivorous in the spring at the beginning of their life (typically the first year of life) so carp are also direct competitors to myriad other species when those other fish are most vulnerable.

Carp also cause indirect harm through disruption of the food pyramid. By outcompeting native fish, the species that depend on those fish as a food source, such as carnivorous fish and birds, are unable to obtain enough food. These effects continue to reverberate across the food chain, affecting native sports fish, birds, and local mammals and reptiles. This is a severe threat to the biodiversity of US riverways.

Carp are also decimating water quality. Some of this is due to their extensive numbers but also because they consume natural filters, such as snails and mussels. As they continue to reproduce and spread rapidly, they are "disrupting the ecology and food web of the large rivers of the Midwest."[3] With no significant demand and government efforts focused on limiting spread to new areas, these harms are likely to increase in years to come.

These fish impose economic harm as well. In addition to outcompeting native species, carp are large fish. While size varies across the four species, they can reach 60-100 pounds and silver carp, in particular, often leap from the water when boats disturb them. While this is one more hurdle among many for commercial workers, it often becomes a deal breaker for people fishing for sport – which in the Midwest alone is a $10 billion industry employing over 143,000 people and bringing in more than $1 billion in state and local tax revenue annually.[4] Without significant market demand, these fish are likely to continue to spread across the country.

Uses to Date

While carp have seen limited market use in the United States, they are a highly nutritious fish prized and used elsewhere in the world. Carp are not bottom feeders, a common misconception. They have some of the highest levels of protein and omega-3 fatty acids found in fish, typically ranking just behind wild-caught salmon, and include very low levels of toxins. They are also rich in vitamins such as A, D, and E and a number of essential minerals, including calcium, phosphorous, and selenium. They are also a very mild-flavored, easily digestible fish.

However, carp are also extremely bony. Like some species of fish such as rainbow trout and perch, carp have Y-shaped intermuscular bones that span their flesh, limiting production of boneless filets to only large sized fish. This, along with common misperceptions of carp, has limited US human consumption demand for the fish. Some groups, such as the Illinois Department of Natural Resources (IDNR), are working to change that. IDNR launched a rebranding campaign involving renaming carp as Copi (short for "copious") and promoting its strong health benefits, mild flavor profile, and its environmental advantages. Beyond marketing, IDNR and a multi-state coalition are working to support removal by encouraging businesses to make use of these fish for a wide range of products.

There are also nascent efforts in the pet food industry. Bones do not pose the same problem in pet food as they do in human food since most pet food today is made from byproducts, including bones – an ingredient that actually contains important nutrients for pets. Some smaller pet food companies, such as Wilder Harrier, Pezzy Pets, and Chippin, are using carp in either pet food or treats. Inversa Leathers, meanwhile, is using carp skin to create leather. However, these markets have been limited both due to lack of widespread demand to date and supply chain hurdles.

Historically, there has been limited carp processing in the United States. Without significant market demand, there hasn't been a reason to invest in processing, but without processing, it's difficult to build a robust-enough supply chain to boost that demand. There are now increasing efforts to tackle this bottleneck. Processors such as Impact Fisheries, Two Rivers, Aquatic Proteins, Colgan Carp Solutions, Moon River Foods, and others offer processing of various sizes and stages. Some are targeting the export market to Asia, where carp is highly sought after and actually overfished, and others are looking at domestic demand across humans, pets, fertilizers, and feed ingredients. Increased and dependable quality and supply will be necessary for any significant market creation, so this is a promising trend, but overall demand and use remain limited.

Top: Copi nuggets, sliders, rangoon, and empanadas were popular at the 2023 Illinois State Fair. *© Mitchell Armentrout / Chicago Sun-Times*

Bottom: Copi fish cakes (Chef Philippe Silverfin). *© Chef Philippe*

Market

Pet Food Background/Supply Chain

The US pet food market is a significant and growing industry. It had revenues of $59.74 billion in 2024 with expected annual growth of 5.03%.[5] This growth is driven by widespread demand. The American Pet Products Association reported that in 2024, 82 million US households, or about 2/3 of all US households, owned a pet.[6] While dry dog food continues to predominate, there is significant demand across different pets and categories.

Each of these major categories has a slightly different production process, but all start with initial processing of either animal proteins, plants, or grains. Dry food, the largest category, is made when ingredients are ground, mixed, and combined with water and steam to form a dough. That dough is then extruded or baked, forming kibbles that can be cut, dried, cooled, and sometimes sprayed with additional flavors or preservatives. Wet food, the second largest market, is made when ingredients are mixed and cooled in sealed containers, such as cans, trays, or pouches. Water is added to achieve desired texture and cooking in the containers ensures sterilization and preservation.

Despite differences in end product, all of these categories make use of a variety of inputs. Farm-based products, such

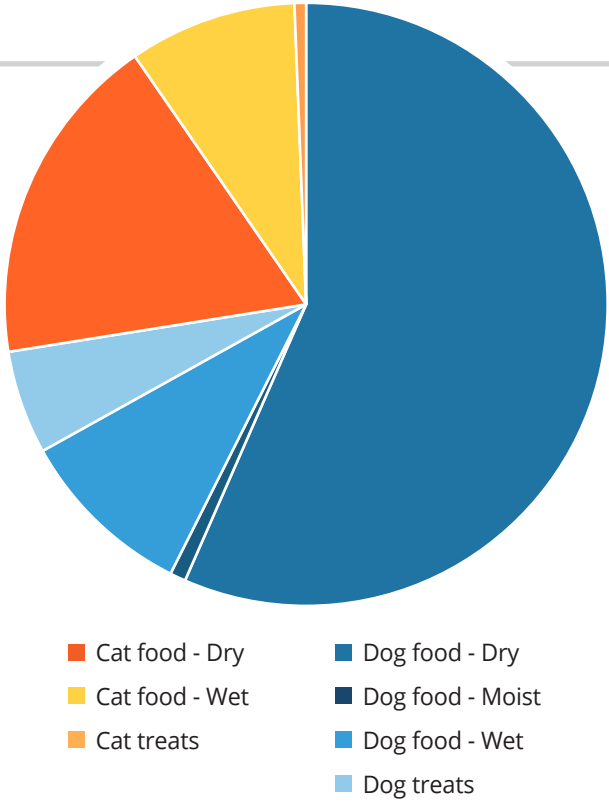
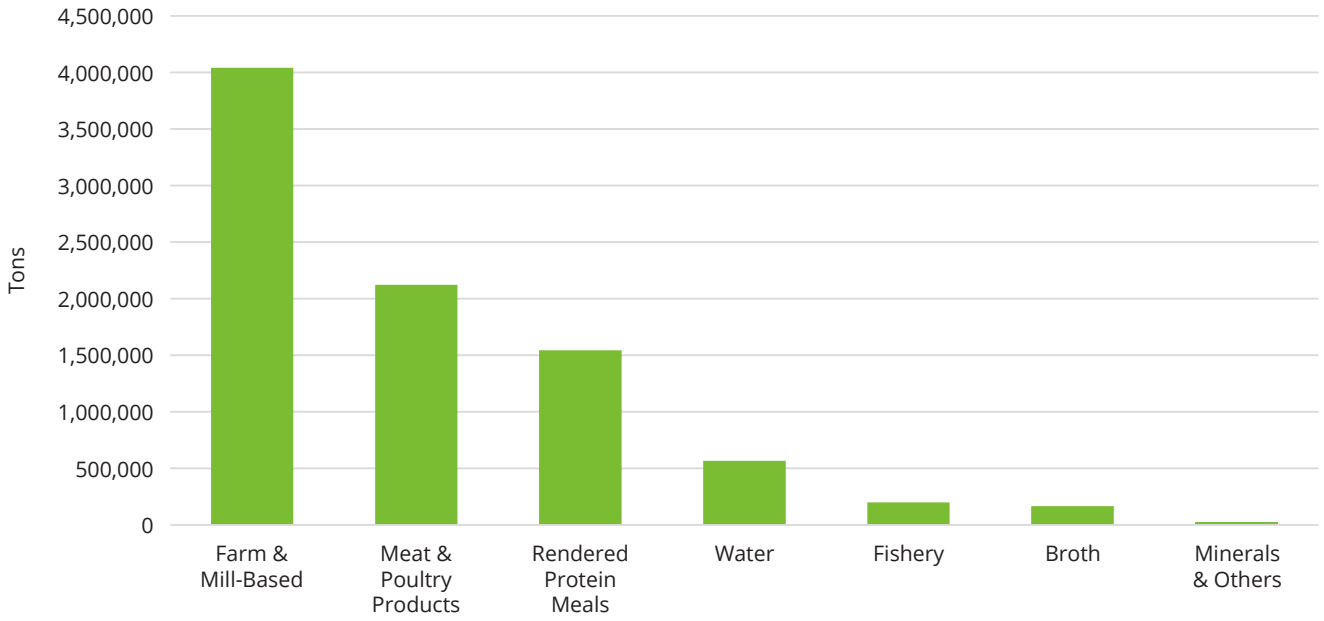


Figure 2: US Retail Pet Food Voume (tons). ***Source:*** *Pet Food Production and Ingredient Analysis, IFEEDER, March 2020.*

Figure 3: US Total Pet Food Ingredients by Category. ***Source:*** *Pet Food Production and Ingredient Analysis, IFEEDER, March 2020.*



as grains, vegetables, and legumes, make up the single largest category but there is growing demand across all proteins and market value is often different than total volume. For example, fishery ingredients make up just 2.3% of total ingredients by tonnage, but 12.9% of ingredient value.[7]

The pet food industry is not only growing but also leads to significant investment across the supply chain. In 2018, the industry generated $4.1 billion in materials, services, equipment, and labor sold to farm suppliers, $5.3 billion in materials and services sold to farmers, and $6.9 billion in farm products sold to pet food manufacturers.[8] The industry also touches nearly every state in the country, though with an extra emphasis in the Midwest. The country's biggest pet food companies, including Nestle Purina PetCare, Mars Petcare Inc, Hill's Pet Nutrition, General Mills, Diamond Pet Foods, and JM Smucker are all based in the Midwest.

The FDA (US Food and Drug Administration) oversees the regulation and safety of pet food, just as it does human food. This is in collaboration with other experts, such as AAFCO (Association of American Feed Control Officials.) Since for many pets, unlike many humans, the food they are given is the same at each meal each day, pet food needs to meet a pet's full nutritional needs throughout their specific life stage. To ensure these standards are met, the US pet food industry is a highly regulated market with strict nutritional requirements.

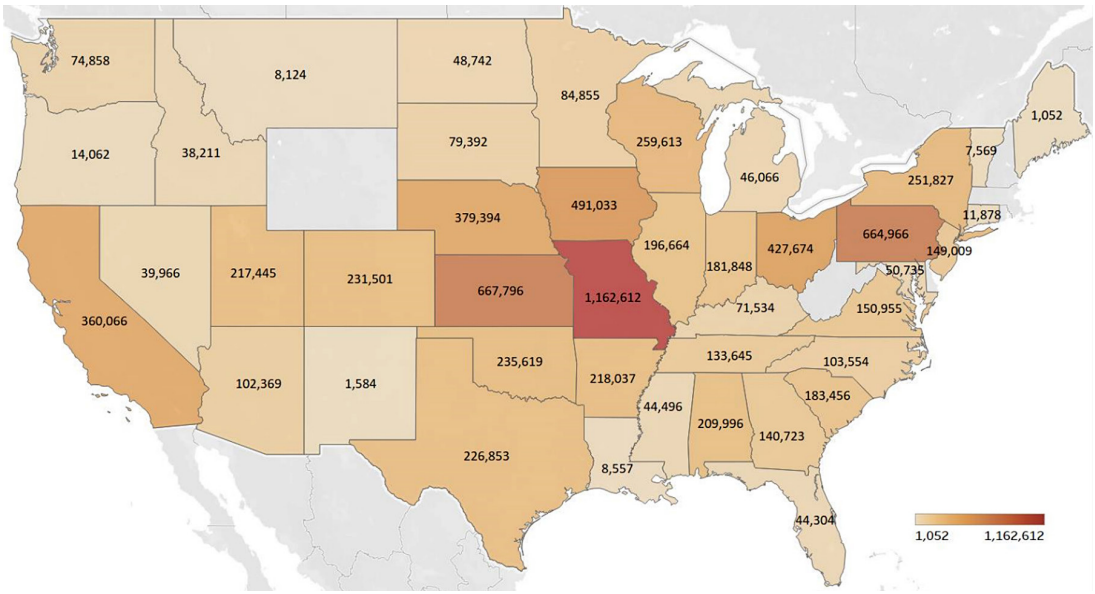
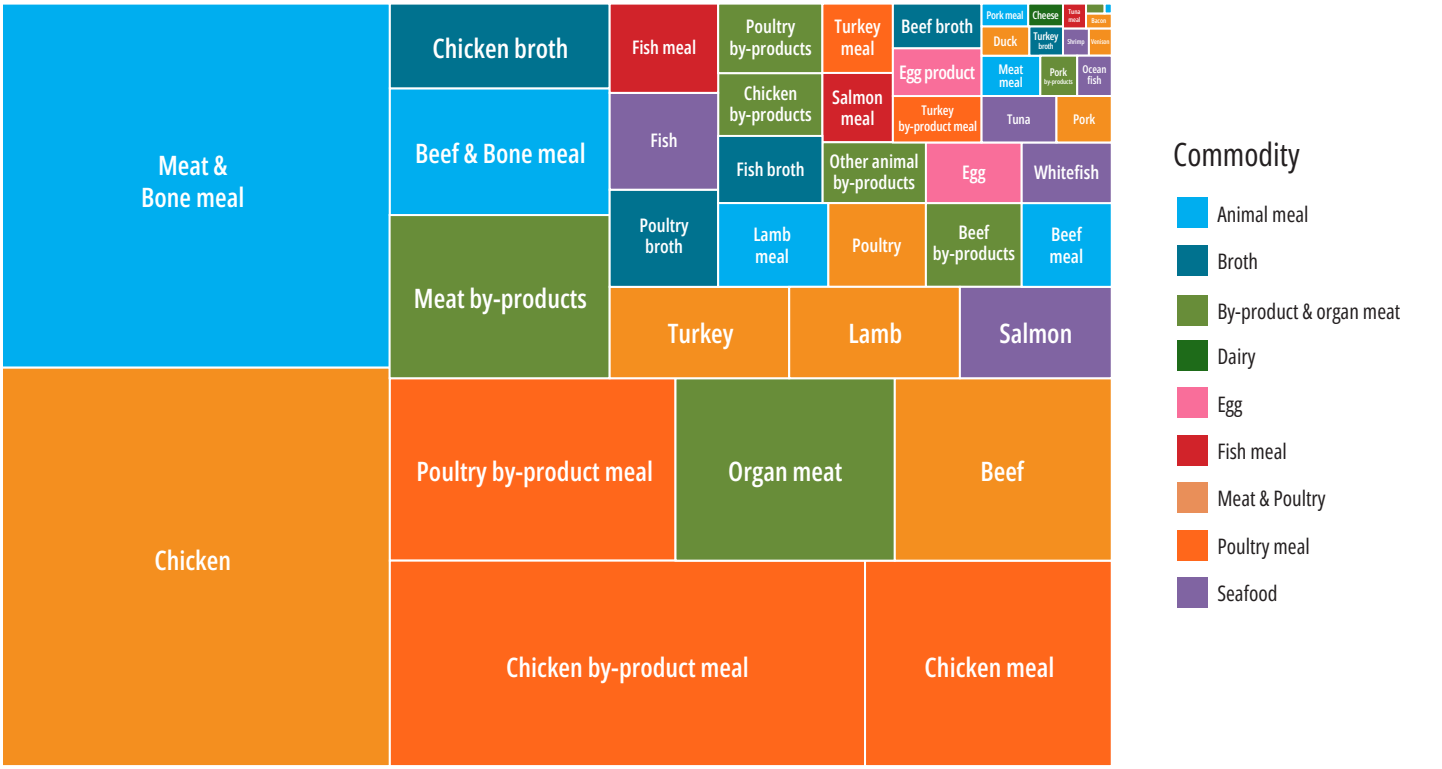


Figure 4: Total Pet Food Ingredients Purchased by State (tons).

Source: *Pet Food Production and Ingredient Analysis, IFEEDER, March 2020.*

Figure 5: Total Pet Food Ingredient Quantities – Animal Protein. ***Source:*** *Pet Food Production and Ingredient Analysis, IFEEDER, March 2020.*



Learnings

The pet food industry continues to evolve and change, driven both by shifting supply chains as well as large-scale trends in demand. Traditionally, the pet food industry has made use of byproducts from human consumption, utilizing parts of animals grown for human food that would not otherwise be used in human meals as well as a variety of plant-based products. While this remains true today, shifts are beginning to occur, driven both by supply and by demand.

On the supply side, pet food demand shows signs of outpacing the availability of human byproducts. The pet food industry has grown at an increasing rate since 2001 and continues to be expected to do so while the rate of animals slaughtered in the US for human consumption has increased slowly or even, at times, plateaued (Figure 6, page 12). When examining these trends and changing volumes, it becomes clear that "if these growth rates continue there will be a point where there are no longer enough animal protein-based ingredients to meet the needs of pet food production."[9] This poses a significant supply chain concern for pet food companies, but also a potentially significant environmental inflection point since if pet food companies are not able to source byproducts, they may need to shift to sourcing animal proteins specifically for pet consumption. It could also change the nutrition equation. While the term byproducts often carries a negative connotation, offal and other parts of animals not used for human consumption often contain the highest level of essential nutrients and vitamins for pets. By using byproducts, pet food companies haven't just been using a product that is environmentally and financially friendly, but also one that actually has been highly nutritious for pets, even if not widely advertised or marketed in that form.

This supply chain bottleneck is also occurring while larger shifts are at play across the industry, including changes in plant ingredient supply and demand, the increasing humanization of pets and a divergence in markets, and related growth in fresh and frozen high-end pet food. There is more and more emphasis on animal-based proteins and the "importance of animal-based protein ingredients is expected to grow in the future with trends towards higher protein diets and pet foods with protein as the first ingredient."[10] However, despite this change, plant-based ingredients still make up the largest single input into pet food.

Unlike animal proteins, corn, soy, and other inputs are often grown for use in pet food rather than depending on byproducts, though for crops like rice, the broken rice left behind is often sourced for pet food or animal feed. Soy has been used in

increasing amounts as an alternative protein source for pets in standard pet food, but it is now facing increased demand in alternative fuels which is driving up the price. Pet food companies may need to switch to alternatives if the cost becomes prohibitive.

There is also a divergence occurring in pet food demand, perhaps best characterized as purchases by pet owners v. pet parents. While pet owners may purchase on price or convenience, pet parents are pushing a humanization trend across the globe. This trend was accelerated when COVID-19

Figure 6: US Produced Pet Food vs. US Animal Slaughter, 2001-2019. ***Source:*** *Hill, Megan, et al. Animal Protein-Based Ingredients in Pet Food: Analysis of Supply Chain and Market. Research in Agricultural and Applied Economics: 2022. Original data from BLS and USDA NASS*

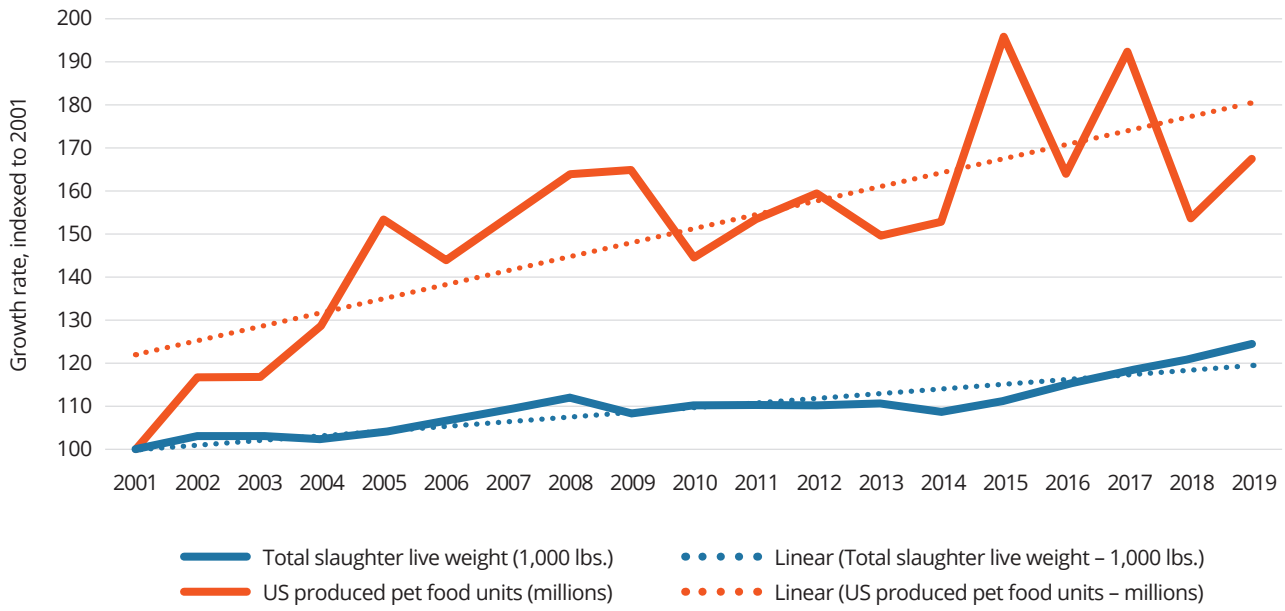
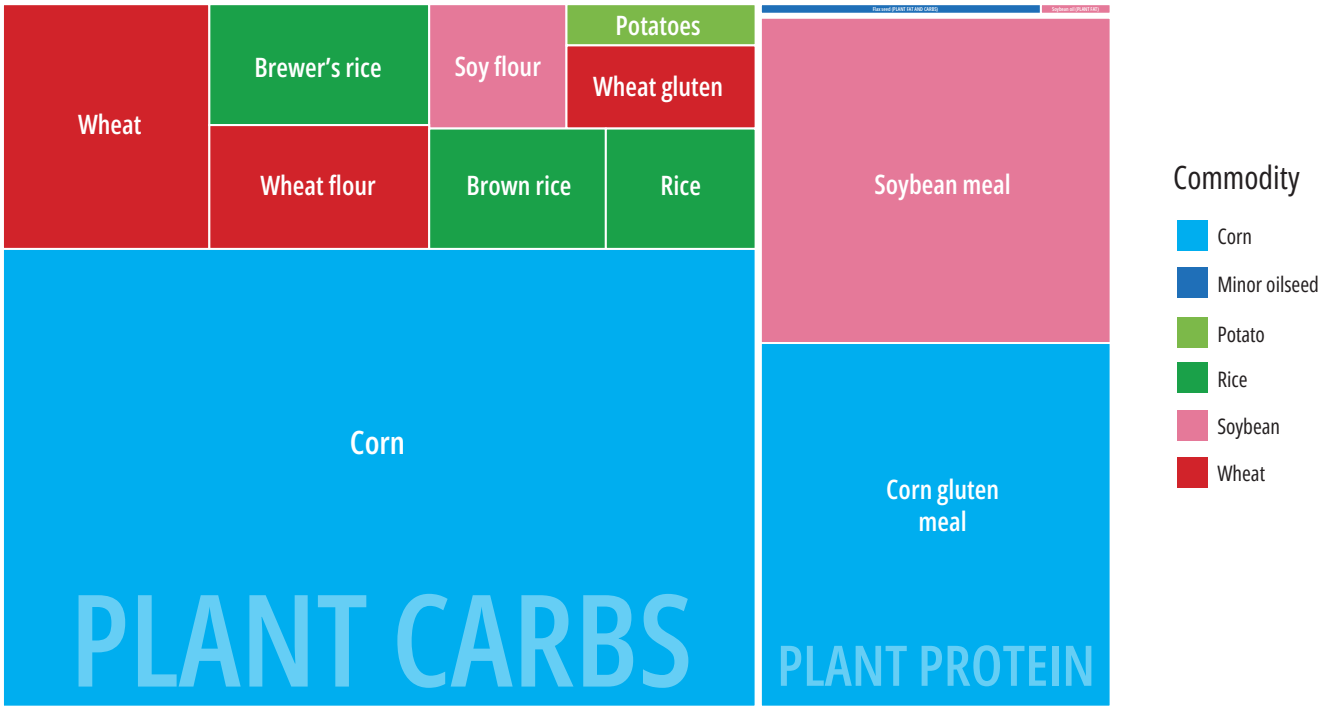


Figure 7: Total Pet Food Ingredient Quantities – Plant Related. ***Source:*** *Pet Food Production and Ingredient Analysis, IFEEDER, March 2020.*



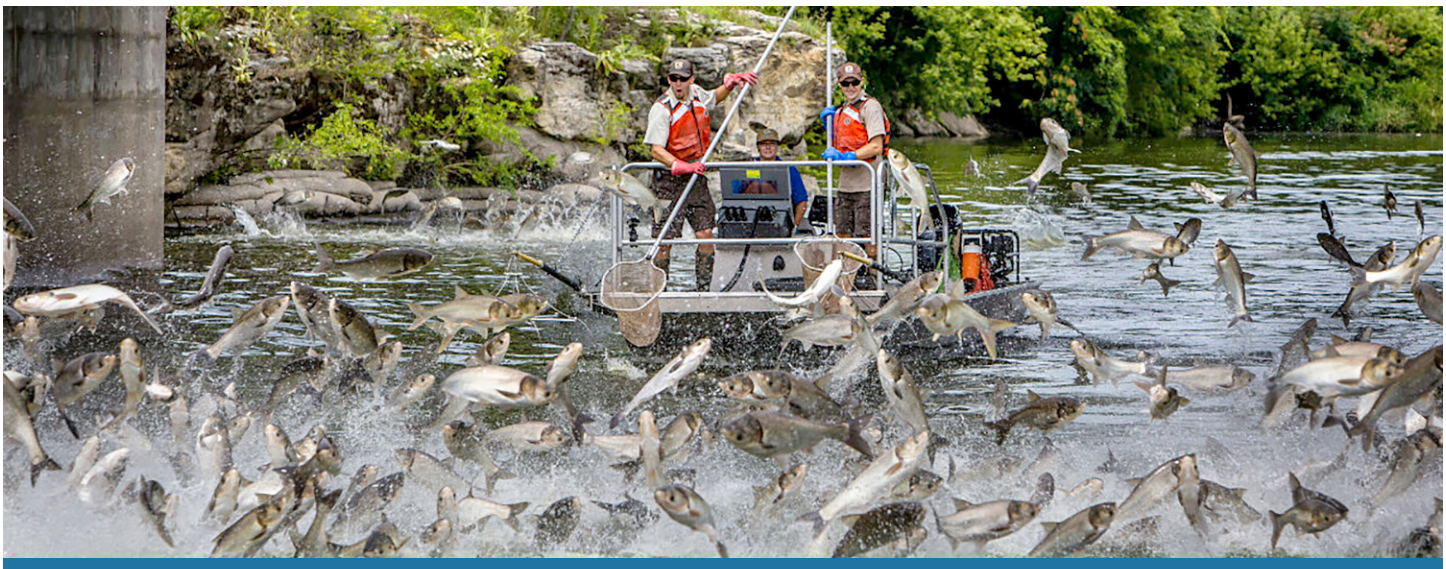
first appeared, leaving pet owners at home with their pets. Pet parents are demanding human-grade products with characteristics that mimic changing human demand, such as grain free products and shorter ingredient lists made up of natural foods. There is also an increasing push around 'food is medicine' in pet food that parallels a similar, growing trend among humans.

These trends are coalescing around fresh and frozen pet food. While still small, these are the fastest growing segments in the pet food industry. This segment saw dollar growth of 21.4% last year and unit growth of 14.3%, one of the only pet food segments to see growth across both of these measures.[11] This is reflected in the growth of high-end pet food brands, such as Ollie's, The Farmer's Dog, and The Honest Kitchen.

These shifts and changes offer competing narratives of where carp may or may not fit into current pet food supply chains. Invasive carp offers many of the benefits that consumers are demanding. It has significant health benefits, is high in protein, and is sourced here in the US and often quite close to pet food manufacturing facilities. However, it also often carries a negative connotation. Pet parents may be particularly hesitant to offer carp to their pets when it's not something they consume themselves. And, while there is an opportunity to highlight 'pets as heroes' helping to fight an invasive species, that would also raise the question why pets should be eating an invasive species. Rather, the effort might better focus on the benefits of the fish.

According to conversations with a number of major pet food companies, it is more likely that carp would be offered within the currently generic 'white fish' category, substituting this locally sourced product for wild-caught fish that are being threatened by overfishing. According to the 2025 AAFCO Official Publication, when using different fish definitions (e.g. fish meal, fish by-products) "if it bears a name descriptive of its kind, it must correspond thereto" and fish meal "is the clean, dried, ground tissue of undecomposed whole fish or fish cuttings, either or both." Since 'white fish' is generally used interchangeably for a variety of mild-flavored, pale fish and, as defined by SeafoodSource, carp meat is white, there seems to be room to explore substituting carp in for other products and labeling it as white fish or white fish meal depending on how it is processed and the parts of the fish that are used. Alternatively, the companies might continue to expand fish offerings as other proteins, both animal and plant, face shifting supply challenges. This could increase supply chain security for pet food companies able to market the health benefits without having to introduce an entirely new product line or educate consumers on carp. However, companies share two main hurdles they would need addressed before investing at scale in carp: (1) understanding the full market potential of a supply chain that is new and unknown and that they worry could be eradicated, since that is assumed to be, and sometimes is, the ultimate goal of addressing an invasive species, and (2) the ecological implications of sourcing an invasive species and how that can be calibrated against their own goals or priorities.

These two challenges would be the same hurdles facing any attempts to create market demand for an invasive species. For invasive carp specifically, though, eradication is not feasible (see Ecological Findings) and the nutrition, nascent efforts, and some other learnings are already available. On the ecological impact side, these are complicated questions to answer, but companies should be able to consider implications across limiting spread, suppressed density, ecosystem services, and biodiversity (see Ecological Findings). It will be important to continue to probe these possibilities and further our learnings to build truly robust market demand and unlock these environmental benefits.



Fishing for invasive silver carp in the Illinois River. *© Ryan Hagerty, USFWS*

Electrofishing silver carp at the Barkley Dam in Kentucky. © *USFWS*

Unintended Consequences

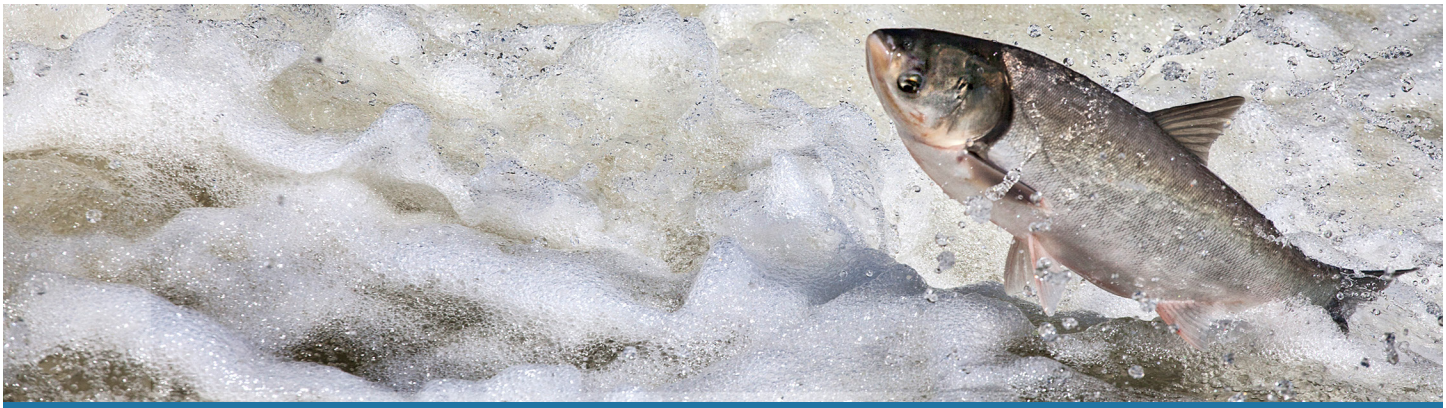
Especially since the goal of sourcing an invasive species at scale is to decrease environmental harm, it is important to consider any unintended consequences that could occur from building a robust new supply chain. There are three potential possibilities to consider here: bycatch, the decreasing use of byproducts in pet food, and encouraging the farming and proliferation of carp.

Carp are decimating native fish species in the Mississippi River and its tributaries, so it is extremely important that large catches of carp not contribute to further harm of other species. However, experts at multiple state divisions of natural resources report that bycatch is very low (~1%) and that commercial fishers can usually target carp very well by using varying net sizes, fishing methods, and targeted locations. As the harvest of carp increases with increased demand, or if the percent of biomass made up of carp decreases, it is possible that bycatch increases. It will be important to continue to monitor and measure this possibility, but at the moment it does not pose a particularly grave concern.

It is also important to consider how carp would fit into the pet food supply chain. Currently, the pet food industry makes significant use of byproducts (see Learnings). If these byproducts weren't being used in the pet food industry, it is possible they would end up in landfills and lead to additional methane emissions. Even though utilizing carp would be good for the environment, it must be weighed against what it is replacing. However, the pet food industry itself is expanding, leading to increased demand for inputs, and the growth rate of the pet food industry is outpacing the rate of increase in animals slaughtered for human consumption. If these rates continue, there will be a period in the future when byproducts can no longer supply the quantity of animal-based proteins needed by the pet food industry. Carp could help fill this gap. Carp could also replace the expansion of plant proteins, which are typically grown specifically for pet food and can lead to increased land conversion. Once again, it will be important to monitor the changes in pet food demand and work with companies on environmental commitments and goals, but this is unlikely to create a significant unintended impact.

Finally, it is possible that market creation could be too successful. If a robust supply chain is created with significant demand for carp, it could lead to incentivizing farming of carp or introducing it to additional waterways for sourcing purposes. In that case, creating market demand would lead to increased spread and proliferation rather than limiting harm. In the near future, this seems unlikely. Carp are extremely prolific and well established in the Mississippi River and its tributaries. While exact quantities are difficult to establish, there are likely many millions of carp in the US and carp make up the large majority

of biomass in many river systems. However, it is possible that calculus shifts in the future. Since carp is an invasive species, there are tight regulations around transporting the fish and various state agencies work to monitor water systems closely. It will be imperative that if carp do fuel a robust supply chain, that agencies work together to closely monitor this potential unintended consequence. While it will not be possible to completely negate this possibility, collaboration and proactive consideration will be the best safeguard.



Silver carp *(Hypophthalmichthys molitrix).* *© Gorlov / iStock*

Ecological Findings

This section is based on work completed by Southern Illinois University. The full paper, "Endpoints of Harvest-Induced Control and Containment of Invasive Carps in North America," is available by request and is in the process of being revised for submission to a scientific journal. All figures in this section are drawn from that paper.

Structure and Goals

Since invasive carp were brought to the US and escaped captivity in the 1970s, they have proliferated, invading a majority of the Mississippi River Basin, including the major tributaries of the Illinois, Missouri, and Ohio Rivers. Since this basin drains nearly half of the country, this is one of the largest invasions in the world. These fish have caused and continue to cause significant economic and environmental harm (see Background) but there has been little success to date in fighting this invasion. State, federal, and international agencies have put together management plans, largely focusing on contracted harvest and physical barriers. However, this is extremely expensive and has seen limited success.

Recognizing that more coordinated effort was needed, the removal of fish via harvest was recognized in 2007 by the National Invasive Carp Management Plan as a viable way to control the population. There has historically been low demand, and therefore a low value, for carp, leaving direct contracted removal as the main source of harvest. The most coordinated effort has been in the Upper Illinois River with the goal of preventing the spread of carp into the Great Lakes. Since 2022, more than 30 million pounds of carp have been removed across riverways, but there is still no solid understanding of how much carp biomass actually exists, so there's little context for that number. In some regions, catch exceeded the previous biomass estimate, highlighting how little is known about the population. The fish clearly remain prolific, pointing to the need for increased demand and higher value to incentivize harvest.

Table 1: Harvest Levels of Carp

Harvest level	% of annually produced biomass removed	Qualitative description
Low	0 –39%	Limited, local removals
Moderate	40 – 80%	Locally impactful removals that are limited in time or space
Intense	>80%	Sustained, geographically broad efforts

In order to understand the potential of market demand, Southern Illinois University and WWF analyzed if carp could still be extirpated from US riverways and, if not, whether harvesting carp could lead to reduced environmental harm. The goal

was to understand the ability for market forces to bring about positive ecological outcomes. Five potential ecological impacts, or endpoints, were considered: eradication, reduced invasion risk, suppressed density, ecosystem services, and biodiversity. To better understand the potential of impact across each of these points, three levels of harvest pressure were analyzed and compared to the impacts of no harvest.

Currently, 10-15 million pounds of carp are removed annually, which is likely in the low category. However, there is little current understanding of the total volume of carp in the Mississippi River Basin, so further research and modeling will be critical to better understand how different patterns impact ecological outcomes.

Potential Impacts

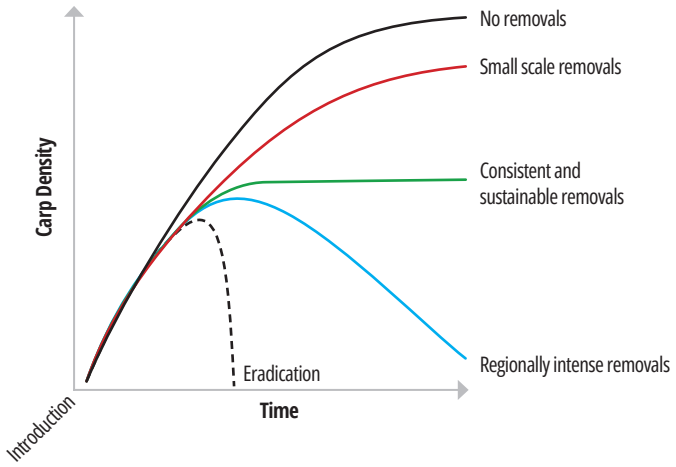
Ideally, the goal of addressing any invasive species would be extirpation. However, even with an intense harvest, it is extremely unlikely that carp would be eradicated from the country's riverways, and the ecological harms that could result from the aggressive extirpation efforts may also be devastating. Carp are already very widespread throughout a complex network of rivers and streams stretching across much of the United States, they have a very high fertility rate, and they are extremely adaptable. Carp populations are also very hardy at reacting to harvest. As large carp are harvested (or die for other reasons), the condition of the surviving carp actually improves so that those remaining fish can reproduce at higher rates. While it is theoretically possible that extremely high and sustained harvest rates that target fish of all sizes (typically harvest doesn't target younger/smaller fish) could ultimately lead to extirpation, it would be very difficult and, even then, likely take a very long time.

Since carp are very likely here to stay, environmental goals switch to minimizing harm. There is the possibility that harvest at some level could bring about improvements in invasion risk, suppressed density, ecosystem services, and biodiversity (see Table 2, page 15). Possibilities across these endpoints vary across harvest level and further research will be needed in some areas to continue to confirm and more precisely target outcomes. The reviewed evidence does not suggest a large risk of worse outcomes from any level of harvest.

Much of the current focus on carp is about limiting spread (i.e. reduced invasion risk) to the Great Lakes. The US government is focused on building physical barriers and various state governments have engaged in contracted harvests. However, carp continue to threaten to spill over into this ecosystem. Harvest, encouraged by market demand, could have a significant impact on curbing this expansion. Especially if fishing is targeted to key source areas, it is likely that even low-to-moderate harvest levels can see benefits in reducing and limiting spread to new areas. And, without incentivized harvest through market demand, it is likely that the physical barriers will ultimately not be enough, and carp will make it into the Great Lakes.

Moderate harvest also is likely to decrease the density of carp. While low levels of harvest may yield benefits limited in time, moderate harvest could suppress the density of carp enough to allow for ecosystems to recover, to reduce risk to boaters, and to see local sports fish populations improve. Regional suppression and reducing the total number of carp is unlikely, but by targeting harvest efforts, local benefits could accrue.

Figure 8: Conceptual diagram of how bigheaded carp density (Y axis) may respond to different levels of removal intensity over time (X axis). Note that because of dispersal between sites, patterns of abundance may be much more complicated over time and space.



Improvement in ecosystem services would include areas such as nutrient abatement, gas exchange, carbon uptake, and decomposition. Carp, because they are omnivorous and extremely dense in population, disrupt the entire food web and likely limit the ability for rivers and streams to efficiently take up nutrients. By reducing carp density, it is likely that there will be a positive impact on ecosystem services. This may include the recovery of large-bodied zooplankton, which provides food to various native fish, especially in early life stages. This would, in turn, allow recovery further up the food chain. However, there are limited studies on this outcome and to truly understand the impact on ecosystem services across various harvest levels, more research will be needed.

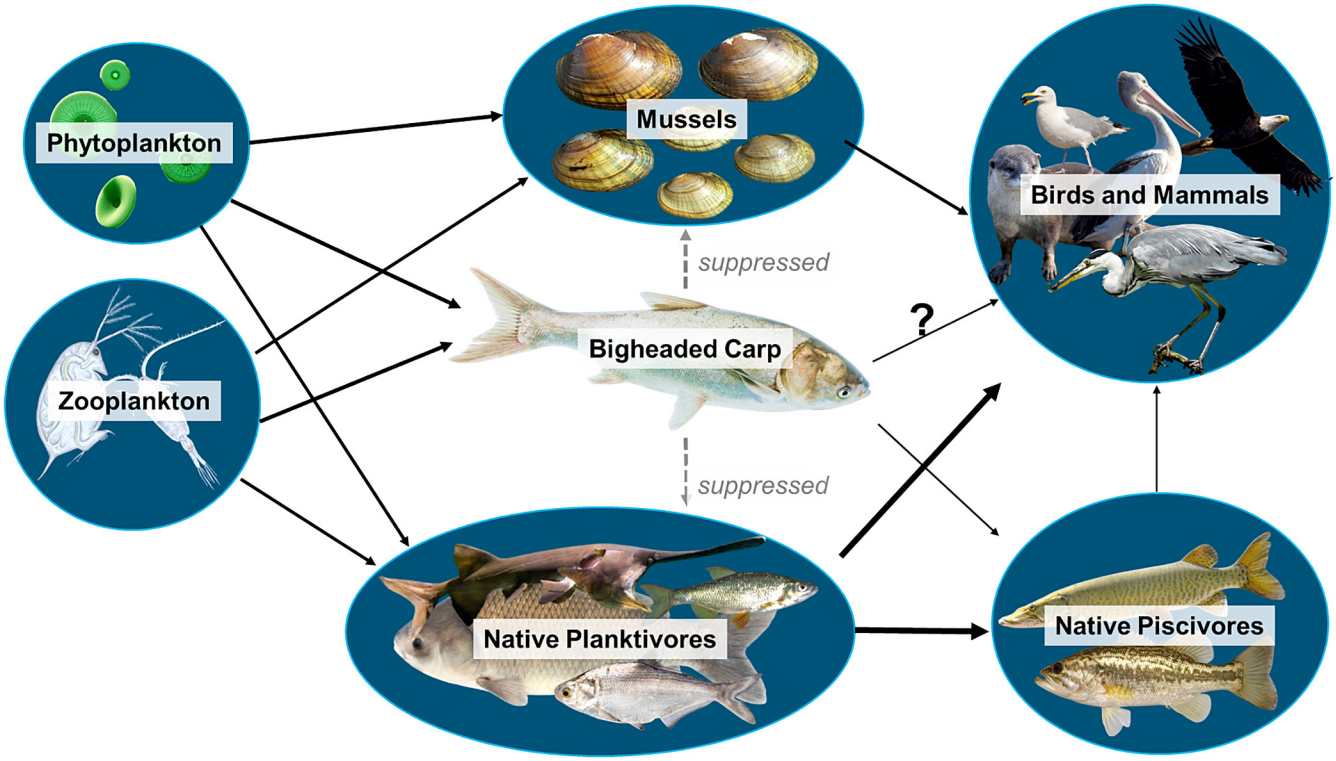
Finally, it is likely that harvest could have a positive impact on biodiversity. Since carp are filter feeders, consuming zooplankton and phytoplankton, they are in the middle of the river food web. This leads to disruption from the middle out,

Table 2: Overview of Five Endpoints Using Harvest to Control Carp.

Endpoint	Harvest level	Response	Likelihood*
Eradication	None	Carp continue to expand (or, in isolated systems, population is limited to carrying capacity of water)	Not applicable
	Low	Density may vary but population unlikely to lessen	Highly unlikely: no evidence or study shows low harvest could cause eradication
	Moderate	Carp density decreases	Unlikely: no evidence or study shows moderate harvest could cause eradication
	Intense	Carp density could trend towards eradication	In isolated systems, eradication may be possible. For open water, it is likely only if harvest has a very high exploitation rate and targets all sizes. Even then, eradication might require a long time.
Reduced Invasion Risk	None	Carp expansion limited by barriers	Not applicable
	Low	Limited local impact on dispersal ability	Likely, though impact may do little to slow overall invasion
	Moderate	Reduced invasion risk if removals target source populations	Highly likely
	Intense	Source populations are diminished, reducing invasion risk	Likely
Suppressed Density	None	Carp abundance limited only by food availability	Not applicable
	Low	Limited short-term decrease; carp will immigrate to replace population	Possible, though replacement of removed fish is likely very quick
	Moderate	Sustained reduction in removal area; source populations unaffected	Likely; further data is needed to better inform population models
	Intense	Sustained regional reduction in density, including source populations	Unknown; data from intense regional harvest schemes is needed
Ecosystem Services	None	Decline in ecosystem services (e.g. unbalanced nutrient cycles, decline in sport fish condition and abundance)	Not applicable
	Low	Slowing the decline of ecosystem services	Unknown; current harvest efforts have not been evidenced to impact services but directed research is needed
	Moderate	Restoration of natural ecosystem services in systems where removal mortality > carp reproduction. Removing carp should result in a removal of their carbon and nutrient stores, deterring algal blooms. Commercial and recreational fishing will increase following increase in native fish.	Unknown; directed research on nutrient cycling and sport fish competition is needed
	Intense	Restored ecosystem services if carp fishing mortality is greater than birth rate, and that fishing pressure is maintained over space and time	Speculative because there has never been a study to support this claim
Biodiversity	None	Carp disrupt the food chain, directly and indirectly	Not applicable
	Low	Plankton abundance may rebound due to their quick reproduction rate, but will likely not be sustainable, as carp density will rebound due to immigration from unharvested areas. Any impact on native planktivores is unlikely.	Likely, but the impact may be too low to quantify
	Moderate	Restoration of native biodiversity in systems where removal mortality > carp reproduction is possible. Recovery of larger, crustaceous zooplankton is most likely due to their high reproductive ability. We may see an increase in planktivorous fish, mussels, and sports fish	Likely, though effects on wildlife may only be noticed after several years
	Intense	Restored native biodiversity if carp fishing > birth rate, and that fishing pressure is maintained over space and time. Since no native species have been extirpated by carp, restoration of historic aquatic community is possible (i.e. an increase in mussels, planktivorous fish, and sports fish). However, the community may also shift towards a new stable state due to stressors not related to carp (e.g. altered flow regimes, other non-carp invasive species.)	Unknown as no invasive species as established as carp has ever been extirpated, thus predicting the trajectory of native biodiversity recovery is challenging

*Likelihood refers to the likelihood of the endpoint occuring

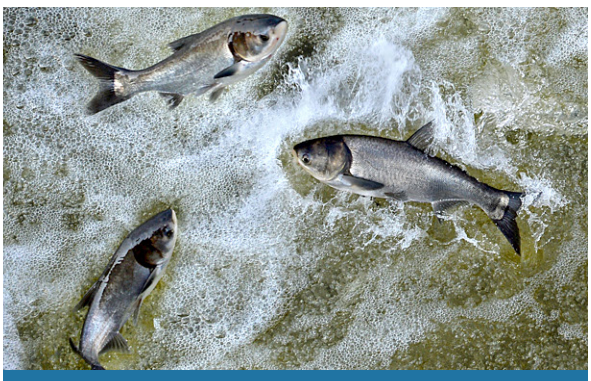
Figure 9: A simplified representation of a central US riverine food web



directly outcompeting and indirectly harming through web disruption. This not only hurts native planktivores but also native predators. Carp end up affecting animals that do not share similar habitat or food preferences. It is likely that with moderate harvest levels, biodiversity should recover as competition for food sources declines and benefits accrue across the food web (Figure 9). This may take some time, though, for the full benefits to reverberate through the river system. Additional research is also needed to better define and understand all of the possibilities.

While additional research is needed, it is clear that sustained market demand for carp is likely to bring environmental benefits. Depending on the market that is created (e.g. pet food) it will also be important to study potential environmental benefits compared to the current status quo. For example, it could bring about environmental harm if carp were replacing byproducts (see Unintended Consequences, pg. 12) but, as is quite likely, if carp are replacing declining fish stocks elsewhere or animal proteins that are directly sourced for pet food, then carp would offer a significantly more sustainable option that limits harm in other areas while also bringing some of the benefits discussed earlier in this section. It will be imperative to continue to monitor and assess possibilities, but with the potential to create wins across the board to the environment, to local economies, and to sourcing businesses.

Grass carp in a Florida lake. © *Sandi Smolker / Shutterstock*



Silver carp near Bagnell Dam, Missouri. © *ginosphotos / iStock*

Clockwise from left: Using gill nets to catch bighead and silver carp in Kentucky. © *Joshua Tomkins, KDFWR ;* Silver carp caught in the Illinois River. © *Evan Garcia - Chicago Tonight*; Big catch of invasive carp pulled from the Illinois River. © *Illinois Department of Natural Resources*

Commercial Fishing Trends and Business Models

Fishing, like many physically demanding jobs at the beginning of lengthy supply chains, has seen a decline in popularity in recent years. Fewer people are becoming commercial fishers and the average age of commercial fishers is drifting older. While some of the reduction in numbers may be due to natural consolidation, it also represents a potential hurdle for sourcing fish at commercial levels and suggests that fishers may have a harder time earning a living wage.

There are fewer commercial licenses today in many midwestern states. Joe McMullen, a River Fish Biologist at the Missouri Department of Conservation, estimates that there are typically 200-300 annually in his state now but closer to 1,000 a couple decades ago. These numbers also hide the true number of people trying to make a living catching fish in the Mississippi and Missouri Rivers. Matt O'Hara, Natural Resource Specialist at the Illinois Department of Natural Resources, as well as Joe McMullen, share that out of the total pool of commercial fishing licenses, about half are typically people seeking those licenses for recreational purposes but need the commercial license to use certain equipment or to host a fish fry at a local community center or church. An additional 40% of licenses typically are sought by people who engage in a small amount of commercial fishing as a side job and just 10% are held by what would be considered a full-time commercial fisher – someone who pursues this as their main career. However, the volume of fish caught across these audiences vary dramatically with those experts suggesting those 10% who are full-time commercial fishers may be responsible for up to 80% of the caught fish. These numbers are echoed when speaking to other similar departments in Midwestern states.

A significant portion of this decline is likely due to the increasingly difficult economic reality. Carp are dominating the waterways but without bringing in the same revenues as native fish populations. Today, a commercial fisher may be able to earn 50-60 cents per pound for catfish, 20-30 cents per pound for buffalo fish, but just 10-15 cents per pound for carp. There are state incentive programs and some are able to offer higher rates, perhaps up to 20 cents per pound, but this typically depends on being able to easily reach processing, which remains in short supply, and still falls short of historic rates for other species. State incentives may also fluctuate or be ended at some point.

These hurdles aren't unique to just the Midwest. The Bureau of Labor Statistics continues to project small but steady declines in the number of fishing and hunting workers across the United States.[12] The BLS cites some of the hurdles that fishers face, such as strenuous physical work, one of the highest levels of occupational injuries and fatalities across all occupations, and long and irregular work schedules. Despite these difficulties, in May 2017 the median annual wage for fishers was just $28,530.[13] This compares to $55,390 across all employees in the United States in 2017.[14]

This represents a risk to communities that depend on these jobs but also to a steady supply chain of carp. If fishers are seeing decreasing gains from strenuous and dangerous jobs, companies and processors may not be able to purchase large amounts of carp or other fish. It will be imperative for all players across the supply chain, fishers, processors, and end companies, to consider how to better integrate fishers into the supply chain and create a chance for long-term financial gain and wealth creation. While this will not be easy, there are examples and learnings from existing fishing co-ops and successes as well as from other groups that face similar hurdles at the start of lengthy supply chains, such as farmers, miners, and garment workers. There are innovative structures that could be put in place as processors come online and this industry is built to ensure lasting financial stability and sustainability.

Existing Fishing Models

While fishers overall are seeing declining wages and numbers, there are individual success stories that provide key considerations and learnings, including community supported fisheries, co-ops, quotas, and integration of sustainability and traceability.

Some fishers have worked together to create community supported fishery (CSF) models, similar to what is sometimes seen in farming. In CSF models, consumers pay an upfront membership fee and get a share of fish throughout the season. Sitka Salmon Shares has done this very successfully by focusing on bringing wild Alaskan-caught salmon to the mainland United States. Catchbox, launched in March 2013, has grown from 70 to more than 300 members by focusing on local and sustainably caught fish.[15] These programs place a greater burden on fishers who need to market and sell directly to consumers, but that also allows fishers to keep the majority of revenue from the caught fish.

Co-operatives, or co-ops, where fishers jointly own an entity, can also bring increased gains — though usually with significantly increased responsibility. Alaska Gold Seafood was founded by fishers who wanted to shorten the supply chain so that instead of splitting revenues across fishers, processors, wholesalers, and retailers, they could earn more of the pie. They have pooled their efforts to vertically integrate and earn more price control. Seafood Producers Cooperative in Alaska and North End Lobster Co-op in Maine have also both created successful models, increasing selling power and providing central locations for aggregation. Meanwhile, Fiskarlaget in Norway focuses on building the entire industry. This co-op, in addition to aggregate sales, offers technical assistance to fishers, recruits youth to enter the industry, and advocates on behalf of fishers with the government. PesCo Pescaderia in Peru, another co-op, is focused on shortening the supply chain by selling directly from fishers to local markets and restaurants and cutting out processors and wholesalers. They also offer training and marketing.

A particularly resonant example is one created by Pezzy Pets, a high-end pet treat company focused on utilizing invasive species. Pezzy Pets started working with small-scale fishermen in Mexico to catch and utilize invasive devil fish (more formally known as armored catfish or *hypostomus plecostomus*). Similarly to carp, devil fish are an invasive species devastating local ecosystems. However, Pezzy Pets was focused on building market demand as well as steady supply. Realizing this wasn't a long-term sustainable strategy, Pezzy Pets worked with local fishers to build a processing plant in Mexico but helped structure it as a fisher-owned co-op. While Pezzy Pets' CEO felt that this was the right thing to do to support the local community and boost economic development, it was also a win-win solution providing a steady supply of devil fish to Pezzy Pets to be made into high-end pet treats.

Pezzy pet treats made from invasive Mexican devil fish, *hypostomus plecostomus (inset, © stammphoto / iStock)* and silver carp. *© Pezzy Pets*

At the regulatory level, government quotas can also be used to boost fisher income. This is a widely used method across the world. While these limits can also be used to protect fishing stocks, limiting supply can lead to higher prices. However, in the case of carp, there are strong environmental reasons to source as many fish as possible and since the supply is already constrained by a lack of demand, quotas are unlikely to work in this situation.

Learnings Across Industries: Processing and Supply Chain Models

Fishers aren't the only group of workers facing aging populations, difficult jobs, and difficult economics at the first step in lengthy supply chains. There are learnings from how similar groups, such as farmers, miners, and garment workers, have used creative models to capture increased wealth. These, as well as new, innovative technologies and changing consumer demands help illustrate potential structures that could bring wealth to fishers while securing consistent supply for all.

Similar to fishers, there have been successful farmer co-ops, such as Route 9 Cooperative, Chestnut Growers Inc, Missouri Northern Pecan Growers, and Grass Roots Farmer Cooperative. Land O'Lakes, a household name, also remains a farmer cooperative to this day. While co-ops do bring significant increased management and business responsibilities, they can also be used strategically to build significant wealth for entities at the start of the supply chain.

Seal the Seasons, meanwhile, has crafted a creative approach to vertical integration and farm partnership. Seal the Seasons, a North Carolina-based processor, sells flash-frozen fruits, vegetables, and value-added products made from that produce. In order to continue their regional sales model without having to make large capital investments to build their own facilities in each state or region, the company created a 'hub and spoke' model. Seal the Seasons partners with a farmer in each region who either already has a flash freezing facility or is willing to work with the company to build one. Seal the Seasons contracts with that farmer, the hub, to purchase frozen fruits and vegetables but also pays that farmer to freeze produce grown by other area farmers, the spokes. The hub farmer sees the most direct economic gain, but the spoke farmers still have access to local processing that didn't previously exist and the higher margins that come from value-added production. A similar model could potentially exist for fishers with local, first-stage processing hubs.

Other farming or food businesses are traditionally owned but have used innovative funding structures to change who has ownership or equity in the long-term. For example, Bhoomi, a sugarcane juice company looking to support minority farmers, needed to raise capital to build a processing facility but wanted to ensure it continued to support partner farmers. In order to accomplish these parallel goals, it was funded by Foodshed Investors, a group of angel investors, using a reverse convertible note – an unusual and innovative deal structured specifically for this situation (though since duplicated). Essentially, the investment was structured to allow buy-back with quarterly payments once the business was launched. It meant the investment operated as debt secured by equity, but the investment didn't appear on the balance sheet so the business was still able to access operating loans as needed. This structure was created so that in the long-term, the business would be ultimately owned by the original entrepreneur and/or other stakeholders rather than an investor.

Meanwhile, Organically Grown Company (OGC) pioneered another innovative structure, the perpetual purposeful trust (PPT). OGC aggregates and distributes organic produce across the United States. Their original founders were dedicated to a stakeholder, mission-drive business model and tried a variety of structures to ensure that the mission would remain at the heart of the company, including a non-profit co-op, an agricultural marketing co-op, an S-Corp, and an ESOP, but it ran into hurdles with all of those. This led to them creating a new model, the PPT, where the trust itself is the legal owner and the business has a fiduciary duty to fulfill its designated purpose. This can be set up in different ways, but OGC set up their PPT so that stakeholders manage the business with profits flowing to investors, employees, the local community, growers, and retailers. There is an elected trust protector committee that monitors that commitments are being met and this structure ensures that stakeholders will remain at the heart of the business for the long-term. While a PPT for fishers may look different, the idea of creating one entity that is owned by a trust with fishers as one of the key stakeholders, along with processors, the local community, and even pet food companies, could provide a creative model to ensure long-lasting and steady supply for all.

Miners are perhaps more similar to fishers than are farmers, who often own a significant asset, i.e. land. Miners, like fishers, also typically face significant work challenges, dangerous conditions, and limited access to the large profits created by end products. However, there are a few examples where miners have been able to earn higher profits while creating sustainable supply across the industry. For example, Artisanal Gold Council (AGC) partners with mining companies and cooperatives to improve the quality of workers' conditions as well as end products. They have worked extensively in Mongolia to build mercury-free mines and support local co-ops and communities and have now proposed a Savings and Credit Cooperative (SCC).[16] The SCC would be a financial institution, partially

funded by the mining operation, but owned and operated by the individual miners. This would allow them to pool resources and access savings and credit. It would also help to formalize the mining industry. There is a similar effort in the Philippines where planetGOLD, another AGC partner, has created a small-scale mining fund to accomplish similar goals. While US riverway fishers do not face the same hurdles as artisanal miners, a similar structure could provide needed capital to fishers looking to expand or invest in their business and a safety net in a weather-dependent business.

The garment industry also provides some creative approaches to benefit its workers. Blue Tin Production in Chicago is a manufacturing co-op owned by immigrants, refugees, and working-class women of color that has vertically integrated to shorten the supply chain and provide wealth creation for its worker-owners. The co-op also offers access to legal and social services, transportation, and childcare. Many of the most successful co-ops go beyond aggregating purchasing power to some level of vertical integration and additional support services.

Finally, blockchain technology and Fishery Investment Funds, a new financial tool being developed to address sustainability in fisheries, may provide an opportunity to earn higher revenues on quality or environmental impact. Some fishing groups are experimenting with blockchain technology to provide traceability from catch to consumer. This can be important for documenting sustainability methods and/or quality control. As consumers continue to ask more questions about where their food, and their pets' food, is sourced, this could provide an option to fetch premium prices. Meanwhile, Fishery Investment Funds, funded by sustainability-focused investors, are being set up to invest in sustainable fishing operations. This provides upfront investment for fishers to upgrade equipment, improve efficiency, or improve new markets. This gives fishers access to capital to invest in their business and a chance to then see higher revenues from a premium product. While these methods may not work for mass-consumer pet food, they would be viable options for the quickly expanding premium pet food market.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Phase II and Next Steps

While there has been significant progress made in learning about the potential of market-based opportunities for carp, it is imperative to transition that research into action while also laying the groundwork for replicability and scalability to other invasive species. WWF plans to take a two-pronged approach, continuing to support the development and reach of carp-based markets while also exploring how to best share learnings to encourage similar efforts across other invasive species.

Carp Supply Chains and Markets

WWF will continue to work to build market demand for carp as a way to use economic forces to address an invasive species and its environmental harm. This will include continuing to work to build processing and secure robust supply, sharing our research to boost market demand, establishing best practices, and exploring additional markets.

WWF's work with carp extends beyond the Markets and Food team. WWF Impact, WWF's impact investing arm, invested in Chippin, an environmentally conscious pet food company, in 2024. This capital will support Chippin to continue building out its carp supply chain and logistics, bring on key supply chain hires, and continue delivering samples to potential clients. This helps Chippin maintain momentum with several potential large-scale buyers. A future processing site that leverages logistics and sustainability advantages has been selected. WWF will continue to work with Chippin in Phase II so that Chippin can establish a processing plant in the region and demonstrate what is possible.

WWF will also continue to build market demand across the pet food industry. Phase I provided a better understanding of market needs, interests, and concerns. As the research has progressed and WWF can share the potential environmental impact of sourcing carp and that extirpation isn't feasible, this market outreach will expand and continue. By sharing these findings broadly and targeting outreach to key companies, WWF expects to be able to continue to build market interest and bring partners across the supply chain to the table.

WWF is also exploring launching a complementary Edible Invasives Initiative (EII), an industry-led association dedicated to amplifying coordination, marketing, promotion, and educational outreach for both human and non-human uses of products derived from invasive species. The central tenet of the EII is to support market growth while utilizing sustainable business practices that also create jobs and increase income for those within the value chain, starting with invasive carp in the Midwest and blue catfish in the Chesapeake drainage systems. The EII will act as a hub for fishers, processors, and allied businesses

to produce and access training materials and resources, engage in zero-waste processing and improve transparency of sustainability targets, develop and launch cohesive market strategies, and create an industry extension entity to inform governance and the public.

Finally, WWF is exploring the launch of an offshoot project to bring healthy, nutritious carp to schools. K-12 schools across the United States serve more than four billion lunches per year, a significant opportunity to influence children's health as well as a chance to turn cafeterias into classrooms, connecting the youth of today more closely to their food system. WWF, the Chef Ann Foundation (CAF), and the National Farm to School Network (NFSN) hope to partner to build a robust river-to-school pathway to integrate invasive carp into school lunches to bring a new, very healthy food to children, continue to fight an invasive species through market demand, and creatively support these goals through learning materials and classroom integration. Since fish served in school lunches tends to be in a form that makes use of a minced product (e.g. fish sticks, fish burgers, fish tacos, etc.) this human market doesn't face the same hurdles as ones that depend on filets. This project is still in its planning stages, but with the goal of launching efforts in fall 2025.

Scaling Across Invasives

The Phase I work, detailed in this paper, has also identified two significant hurdles to creating market demand for carp that would apply more broadly to invasive species: (1) companies do not want to invest in understanding and exploring full market potential of a supply chain that is new and unknown and that could be eradicated, since that would be the ultimate goal of addressing an invasive species, and (2) companies do not yet understand the ecological implications of sourcing an invasive species and how that can be calibrated against their goals or priorities. While WWF has engaged in work to address these two hurdles for carp, it would not be feasible to do so for all potential invasive species.

Currently, there is little codified knowledge about the overlap between invasives and economics. In Phase II, WWF will work to lay the necessary groundwork to spur further efforts and approaches to other invasive species that consider the hurdles we have identified, including developing an archetype or framework for judging market potential and ecological impact of other species. In this next phase, WWF will develop a matrix of invasive species to judge market potential and complete high-level economic and ecological impact assessments of top identified species. These learnings and frameworks will be shared publicly alongside a broader archetype to showcase how ecological and market needs must be united to effectively create markets to address invasive species. In addition to publicizing this work, WWF will encourage additional research building on our findings. This may include showcasing the work at sessions or workshops at existing conferences and/or partnering with a journal to put out a special topic issue related to this work. WWF's goal would be to share how a provocative, market-based approach to research can highlight what industries need and lead to further work across a wide array of species.

Conclusion

Invasive species are a major threat worldwide. They have led to the extinction of at least 142 species around the world and currently threaten around 500.[17] This issue is estimated to have cost the world $1.3 trillion over the past 50 years, with quickly increasing costs.[18] Yet, to date, efforts have largely concentrated on removal, a costly and time-intensive battle. While this method may continue to be needed for many species, others may be ripe for a market-based approach that tackles removal of invasive species in an economically and environmentally feasible way while bringing benefits to local regions. However, few efforts have succeeded in this space and better knowledge is needed to inform investments, make decisions, and drive policy.

Building robust market demand for carp provides a chance to address environmental harm to the broader Mississippi River Basin, boost economic development in the Midwest, and even improve the environmental footprint of pet food supply chains. However, it also provides a chance to gain valuable feedback and to serve as a proof-of-concept of an additional tool to fight invasive species. While markets-based approaches will not be the right solution for all invasives, if successful, this project could become a new model of another option and spur further research, learnings, and action worldwide.

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