United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/national-list/petitioned

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Fish-Based Fertilizers

Crops

Identification of Petitioned Substance

Chemical Names:
Not applicable

Other Names:
Fish emulsions
Fish hydrolysate
Fish soluble nutrients (solubles)
Fish silage
Liquid fish
Fish meal

Trade Names:
Numerable

CAS Numbers:
97675-81-5 (Fish meal)

Other Codes:
EINECS 307-654-9 (Fish meal)

Summary of Petitioned Use

Fish-based fertilizers are allowed under the USDA National Organic Program (NOP) regulations when nonsynthetic (7 CFR 205.105). For use as plant or soil amendments, synthetic liquid fish products are allowed when pH adjusted to no lower than 3.5 with synthetic sulfuric, citric, or phosphoric acid (7 CFR 205.601(j)(8)). Synthetic liquid fish products were included in the 2000 NOP Final Rule (Vol. 65 Fed. Reg. No. 246, 2000), and fish emulsions are statutorily allowed within OFPA (7 U.S.C. § 6517(c)(1)(B)(i)).

The National Organic Standards Board (NOSB) Crops Subcommittee considered whether wild, native fish harvested solely for fertilizer production should be prohibited during their Spring 2018 meeting. This technical report is limited in scope to focus only on responses to specific questions from the NOSB Crops Subcommittee and supplements the 2006 Technical Evaluation Report (TR) on liquid fish products.

For the purposes of this report, weight measurement units are typically noted in millions of metric tons (megatons), or MMT. One metric ton (MT) is equivalent to 1,000 kilograms or 2,204 pounds.

Characterization of Petitioned Substance

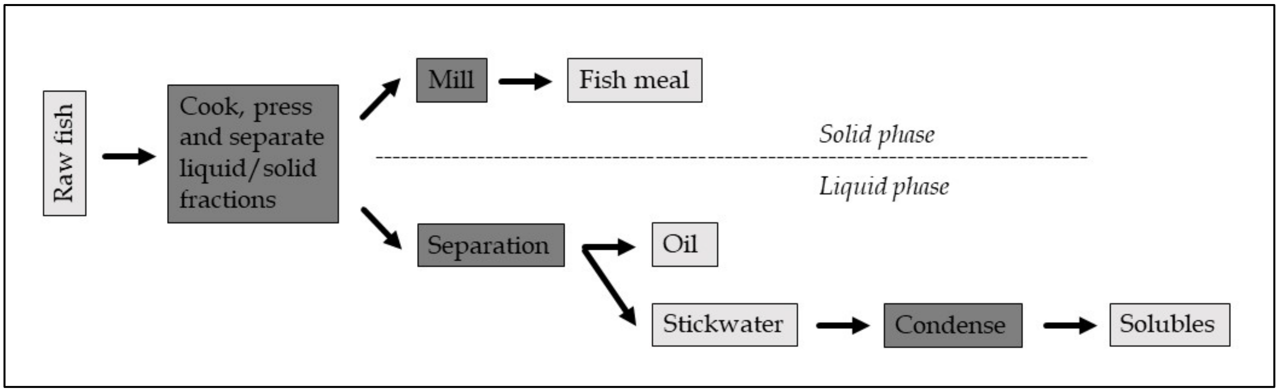
<u>**Composition of the Substance:**</u>
The Technical Evaluation Report on liquid fish products (USDA, 2006) provides details on the composition, specific use, and source of liquid fish products. This limited scope report will include a few overlapping details that are relevant to the focus questions requested by the NOSB.

Fish-based fertilizers occur in liquid and dry forms. Dry forms are typically composed of the same materials as liquid products, though some dry products contain fish meal, which is not typically found in liquid formulations (OMRI, 2019a). Ingredients are usually in one of the following forms: solubles, hydrolysates, or meals. Solubles and hydrolysates are both commonly stabilized by adding acids to prevent putrefaction or to stop the activity of enzymes.

Fish solubles and meal
Fish solubles are an aqueous byproduct of fish meal and oil production, and therefore related by a common overall manufacturing process known as "wet reduction," shown in Figure 1 (FAO, 1986; Kim, 2014; OMRI, 2019a). Fish well-suited to the process (e.g., anchoveta, sardine, or menhaden species) are harvested and transported to processing plants. The process includes cooking and pressing the fish, then separating out the solid and liquid phases. The solid phase is processed to create meal, while the liquid phase is separated

further into oil and "stickwater" phases. The oil is separated from the stickwater in a centrifuge, while the stickwater (hereafter referred to as "solubles") is concentrated in an evaporator. In some cases, concentrated solubles are added back into the fish meal; other times they are sold as their own product. Historically, solubles were considered a waste product of the meal and oil production process, but now are used in animal feeds, fertilizers, and other applications (FAO, 1986; Kim, 2014; OMRI, 2019a).

Figure 1: Simplified meal, oil, and solubles wet reduction process flow chart



Fish hydrolysates

Hydrolysates can be produced through a variety of means, including enzymatic, acid, or alkaline hydrolysis processes that chemically reduce fish protein into readily available nutrients (Kristinsson & Rasco, 2000). For enzyme hydrolysis, additional acids are sometimes used as stabilizers to prevent microbial spoilage, or to stop the enzymatic process (USDA, 2006). After fish or fish waste is minced, it is added to a tank (sometimes with salt) and allowed to break down, either by naturally occurring enzymes within the fish or with the addition of proteolytic enzymes (Kristinsson & Rasco, 2000; USDA, 2006; OMRI, 2019a). Once the proteins are broken down to the desired amount, the enzymatic process is stopped though heating or pH adjustment.

Specific Uses of the Substance:

Fish and fish scraps were commonly used as raw material for agricultural fertilizers until petroleum-based chemical fertilizers became widely available after World War II (Aung et al., 1984). Currently, fish-based fertilizers are used in organic agriculture for their relatively high macronutrient content, especially nitrogen and calcium (Illera-Vives, Labandeira, Brito, & López-Fabal, 2015).

Fish meal is used extensively in both terrestrial and aquatic animal feeds (Bimbo & Crowther, 1992). Fish oil is used in human food as well as in animal feeds (Bimbo & Crowther, 1992), and as a nutritional supplement for human consumption (Jenkins, et al., 2009). Fish solubles are sometimes added back to fish meal, producing "whole" fish meal that is used in animal feed or as a fertilizer (FAO, 1986; Wu & Bechtel, 2012; OMRI, 2019a).

Source or Origin of the Substance:

Table 1 summarizes the sources of fish used to produce fish-based fertilizers[1] listed by the Organic Materials Review Institute (OMRI) as of June 10, 2019 (OMRI, 2019a). For lack of other available sources of data, the authors infer that these products are representative of the fish-based fertilizer products used on organic operations.

[1] Products listed by OMRI in the following NOP Crop Fertilizers and Soil Amendments (CF) categories: *Fish Meal and Powder*; *Fish Products*; *Fish Products, Liquid, Stabilized*; *Fish Products, Multi-Ingredient* (OMRI, 2019c).

Table 1: Source of fish material used in OMRI listed products

Source	# of products	% of products
Fish waste (waste left over after market fish are processed)	54	43.5%
Bycatch and mortality (inadvertently caught or damaged when harvesting fish for non-fertilizer use)	4	3.2%
Meal, oil, and solubles (fish harvested for wet reduction process)	39	31.5%
Fish waste + bycatch and mortalities (combination)	16	12.9%
Fish waste + meal, oil, and solubles (combination)	11	8.9%
Fish sourced specifically/only for use as fertilizer	0	0%

Of the 124 fish-based fertilizers listed by OMRI, 76 percent contained at least some wild fish, 15 percent contained at least some farmed fish, and 27 percent contained fish where it was not possible to tell if a source was farmed or wild (OMRI, 2019a). Products in some cases used various combinations of wild, farmed, and unknown fish.[2] Twelve percent of products contained at least some fish meal, 45 percent contained at least some fish hydrolysate, and 43 percent contained at least some fish solubles.[3] One product contained both meal and solubles, and was counted in both groups.

It is worth noting that in Table 1, fish harvested for meal, oil, and solubles were not considered to be harvested solely for fertilizer production. The majority of fish-based fertilizers derived from the wet reduction process contain solubles—a material that is sometimes considered a byproduct of the process. A few products contain meal, but they do not also include fish oil; therefore, only a portion of the saleable fish biomass is utilized specifically for fertilizer and one cannot say that the fish were harvested exclusively for fertilizer use. An analogous example would be beef cows raised for steaks, ground meat, renderings and leather; those animals were not raised *exclusively* for any single one of those materials. Furthermore, only 2 percent of products contained fish meal that was derived from fish harvested specifically for wet reduction. The remaining 10 percent of products containing fish meal are derived from fish waste that undergoes further processing.

Fish harvest rates

In order to establish a frame of reference for evaluating the focus questions within this report, it is useful to include the scale of fish harvested for all uses, whether farmed or wild-harvested, and the proportion of fish collected for non-human food use (such as in fertilizers). While no exact value was found, the proportion of fish incorporated into fertilizers is likely very small compared to most other uses, such as for human consumption and animal feed.

The countries with the highest fish production rates (farmed and wild) are China, Indonesia, India, the United States, and Russia (FAO, 2016). Worldwide production of fish, crustaceans, mollusks, and other aquatic animals (excluding mammals and reptiles) in 2016 reached 171 MMT and $362 billion USD (FAO, 2018). Of that, aquaculture[4] contributed 47 percent to production and is largely responsible for the increase

[2] For this reason, the sum of these percentages do not add up to 100%; products were counted in farmed, wild, and unknown fish source groups as was applicable.

[3] Adding products **containing** fish meal and fish solubles does not yield the same value as is noted for fish **harvested for** "Meal, oil, and solubles" because some meal, oil, and solubles are produced from fish originally harvested for other purposes, and are thus accounted for in other categories in Table 1. Waste from fish harvested for other purposes is sometimes diverted into fish meal production.

[4] Defined as the practice of cultivating aquatic animals for food.

in total production since the late 1980s (FAO, 2018). This is likely due to the global harvesting rate from wild fisheries having approached its upper limit at that time (Botsford, Castilla, & Peterson, 1997). Globally, inland waterways contribute 12.8 percent to the total of capture fisheries (methods excluding aquaculture) (FAO, 2018).

While the apparent consumption of fish has continually increased since at least 1950, the amount of fish used for non-food purposes has remained relatively steady since the mid-1990s (FAO, 2018). In 2016, 19.7 MMT of fish were used for non-food purposes, whereas 151.2 MMT were used for human consumption[5] (FAO, 2018). Fish products destined for non-food uses include fish meal, fish oil, and other products which may be used in aquaculture, livestock feeds, baits, medicines, and fertilizers (FAO, 2016). It is the non-food use proportion, combined with fish processing waste (not accounted for in these statistics), that relates to fish-based fertilizers.

Available information from the Food and Agriculture Organization (FAO) and other sources does not resolve below the "non-food uses" characterization, which represents 11.5 percent of the total global production; it is therefore not possible to determine how much fish is used as terrestrial fertilizer. As an additional complicating factor, the FAO compiles information provided by individual member countries, and this information in some cases may be misreported or estimated (Watson & Pauly, 2001; FAO, 2018). Using additional data not included in FAO reports (such as from artisanal and recreational fisheries, and discarded bycatch) Pauly and Zeller estimated that actual catches between 1950 and 2010 were 50 percent higher than reported, with a peak catch of 130 MMT, far above the FAO estimates (2016). They also estimate that subsequent declines in annual catches were stronger than noted in FAO data.

In the United States, the monetary value of "other" industrial processed fisheries and aquaculture products represented 2 percent ($188.3 million) of the total value of U.S. processed fishery products ($11.98 billion) during 2016 and 2017. These "other" industrial fisheries and aquaculture products include numerous materials, such as animal feeds, kelp products, and dry and liquid fertilizers (NMFS, 2017). Between 2008 and 2017, domestic annual production of fish scrap and meal (a subset of which is used for "other" industrial products like fertilizer) averaged 0.246 MMT (542 million pounds) (NMFS, 2017). The U.S. imported 0.062 MMT (138 million pounds) of nonedible meal and scrap in 2017 (NMFS, 2017); information was not found that indicated how much of that material was used in fertilizer.

In 2016, the most caught species were Alaska pollock, anchoveta, Skipjack tuna, Atlantic herring, and Pacific chub mackerel (FAO, 2016). The total catch in 2016 was 2 MMT less than in 2015. The United States followed China, Indonesia, and India as the fourth largest fish capture producer, with 4.9 MMT (FAO, 2016).

Approved Legal Uses of the Substance:

Fish emulsions are included in OFPA: 7 U.S.C. § 6517(c)(1)(B)(i), and liquid fish products are included on the National List as synthetic plant or soil amendments which are allowed for use in organic crop production (7 CFR 205.601(j)(8); formerly (j)(7)). Fish meal is allowed in organic crop production when nonsynthetic (7 CFR 205.105).

Fish harvesting in the United States is governed under the Magnuson-Stevens Fishery Conservation and Management Act (MSA), which was passed in 1976 and amended in 1996 and 2007 (NOAA, 2019a). The act establishes conservation and management requirements for the United States, including inside of the U.S. Exclusive Economic Zone: over the continental shelf and up to other nations' territories (3–200 nautical miles off of the U.S. coastline) (NMFS, 2017). Under the MSA, the United States requires that U.S. fisheries are monitored and managed to produce a "maximum sustainable yield"—that is, fish populations are kept above specific determined levels (NOAA, 2017). Additionally, the Marine Mammal Protection Act (MMPA) and Endangered Species Act (ESA) provide protection for whales, dolphins, porpoises, seals, sea lions, and endangered species (NOAA, 2017). There are eight regional fishery management councils that create

[5] These statistics reflect fish biomass pre-processing; waste created during fish processing that is redirected to other processing streams (such as fish meal/oil reduction) is considered under the original pre-processing use.

management plans for different fisheries. These management plans may include elements such as harvest quotas, fishing gear restrictions, and boundaries to protect sensitive areas (NOAA, 2017). Enforcement is carried out by the National Oceanic and Atmospheric Administration (NOAA) Office of Law Enforcement.

Focus Areas Requested by NOSB Crops Subcommittee

Focus Question 1. Please provide universally agreed upon definitions of "wild, native fish," "wild-harvested," and "invasive species."

A universally recognized definition for the term "wild, native fish" does not exist. A proposed definition for this term, based on published USDA definitions for "native species" and "wild fish," is included below.

Under the USDA, a native species is: *"with respect to a particular ecosystem, a species that, other than as a result of an introduction, historically occurred or currently occurs in that ecosystem"* (USDA National Invasive Species Information Center, 1999). Wild fish are defined as: *"naturally born or hatchery-raised fish and shellfish harvested in the wild, and caught, taken, or harvested from non-controlled waters or beds; and fillets, steaks, nuggets, and any other flesh from a wild fish or shellfish"* (7 CFR 60.133) and excludes the term from *"net-pen aquacultural or other farm-raised fish"* (7 U.S.C. § 1638(7)). However, under NOAA regulations, wild fish are defined as: *"fish that are not propagated or reared by humans"* (50 CFR 622.2). For the purposes of this report, the term "wild, native fish" will rely on the USDA description for wild fish because the distinction between hatchery and non-hatchery raised native fish is not central to the issue before the NOSB and the NOP as described.

Proposed definition for wild, native fish: an undomesticated fish species that has historically occurred (without human introduction) in a given ecosystem. Wild, native fish may be hatchery raised (if subsequently released) or born without human intervention, but do not include net-penned or farm-raised fish.

A universally recognized definition for the term "wild-harvested" was also not found in the literature reviewed for this report. Definitions for similar or related terms were therefore used to construct this report's definition.

Under the NOP regulations, a wild crop is: *"any plant or portion of a plant that is collected or harvested from a site that is not maintained under cultivation or other agricultural management"* (7 CFR 205.2). The NOP describes but does not define "wild crop harvesting" for certification purposes in Guidance NOP 5022; the guidance also excludes animal species (2011). While a definition for "harvest" applicable to fish could not be found, under Title 50 of the CFR (NOAA), a harvesting vessel is defined as: *"a vessel involved in the attempt or actual catching, taking or harvesting of fish, or any activity that can reasonably be expected to result in the catching, taking or harvesting of fish"* (50 CFR 660.502). A "harvest event" is: *"for wild-capture fisheries, the landing of fish in port or offloading of fish from a fishing vessel that caught the fish to a carrier vessel at sea or in port"* (50 CFR 300.321). Merriam-Webster defines wild as: *"living in a state of nature and not ordinarily tame or domesticated"* (2019), and this term appears to be consistent with the usage of the term in federal regulations. Within the MSA, harvested fish is defined as: *"fish caught, taken, or harvested by vessels of the United States within any fishery regulated under this Act"* (16 U.S.C. § 1802). Fishing means: *"The catching, taking, or harvesting of fish"* (50 CFR 253.1); the terms fishing and harvesting appear synonymous.

Proposed definition for wild-harvested fish: the act of taking undomesticated fish (native or non-native) from their habitat through a variety of means, including hand lines and nets, but excluding net pens and other fish farming practices. The term includes "wild-caught" fish.

Under the USDA, an invasive species is: *"an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health."* An alien species is: *"with respect to a particular ecosystem, any species, including its seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem"* (USDA National Invasive Species Information Center, 1999). The U.S. Fish &

Wildlife Service defines an aquatic invasive species as: *"a non-native aquatic species that invades ecosystems beyond their natural, historic range"* (2019).

Definition of invasive species: a non-native species (including seeds, eggs, or other biological material) capable of propagating, and likely to cause economic, environmental, or human harm.

Other terms useful to define for the purposes of this report:

Fishery: *"1. Generally, a fishery is an activity leading to harvesting of fish. It may involve capture of wild fish or raising of fish through aquaculture; 2. A unit determined by an authority or other entity that is engaged in raising or harvesting fish. Typically, the unit is defined in terms of some or all of the following: people involved, species or type of fish, area of water or seabed, method of fishing, class of boats, and purpose of the activities; 3. The combination of fish and fishers in a region, the latter fishing for similar or the same species with similar or the same gear types"* (NOAA, 2006).

Bycatch: *"the incidental or discarded catch of protected living marine resources or entanglement of such resources with fishing gear"* (50 CFR 300.201). Under the MSA, bycatch are *"fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards. Such term does not include fish released alive under a recreational catch and release fishery management program"* (16 U.S.C. § 1802).

Bycatch can be fish that have no economic value (economic bycatch), fish that must be discarded because of management regulations such as gender-specific allowances or size limits (regulatory bycatch), or fish that are killed by fishing gear itself (collateral mortality) (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003; Pew Oceans Commission, 2003).

Economic discards: *"fish which are the target of a fishery, but which are not retained because they are of an undesirable size, sex, or quality, or for other economic reasons"* (16 U.S.C. § 1802).

Collapse: "*a 90% reduction in a wild fish stock*" (Schreiber & Halliday, 2013).

Focus Question 2. Is any new information available about the impact of fish fertilizer manufacturing on the sustainability and health of wild, native fish stocks harvested solely for fertilizer production?

Yes, this report presents new information regarding the *current* use of wild, native fish for production of fish-based fertilizers, as well as an overview of the *potential* impacts on the sustainability and health of wild, native fish stocks from fishing activity generally (not specific to fish fertilizer manufacturing).

Based on available data, wild, native fish are not harvested solely for fertilizer production (see Table 1, in *Specific Uses of the Substance*) (OMRI, 2019a). Rather, fish waste or otherwise unusable material is generally used as the starting material for fish-based fertilizers. Two percent of OMRI Listed fertilizers are made from fish that are harvested for the coproduction of meal and oil (with solubles as either a byproduct or additional coproduct) (OMRI, 2019a). Fish meal is a commodity ingredient that can be used for other applications (such as both terrestrial and aquatic animal feeds) and is produced simultaneously with fish oil (and solubles). See *Source or Origin of the Substance* for a discussion of why products made fish sourced for this purpose are not considered to be "harvested solely for fertilizer production" within this report.

Information specific to the impact of fish fertilizer manufacturing on the sustainability and health of wild, native fish stocks was not found. Some reports suggest diverting fish waste (of all types) to fertilizer production as a means to dispose of fish biomass more economically and in an environmentally sensitive manner (Aranganathan & Rajasree, 2016; Dao & Kim, 2011; Dominy, Sato, Ju, & Mitsuyasu, 2014; Herpandi, Huda, & Nadiah, 2011); however, these reports do not demonstrate that this is, in reality, a sustainable practice.

Fish fertilizers in general are niche products compared to other uses of fish. Basic data, such as the amount of fish fertilizer produced nationally or globally, were not found. The FAO is the only organization that maintains global fish harvesting statistics (Watson & Pauly, 2001). As basic information specific to fish fertilizer manufacturing is limited, the remainder of this report will extrapolate information from the impacts of harvesting fish and utilizing fish waste byproducts generally.

Impact of fishing on the sustainability and health of wild, native fish stocks

In general, commercial fishing has been detrimental to the sustainability and health of many wild, native fish stocks. The most recently available NOAA *Status of Stocks 2017* report to Congress shows that of the 474 tracked fisheries within the United States region, 15 percent are "overfished"[6] (NOAA, 2017). From 2000 to 2017, 44 stocks previously considered overfished were rebuilt; however, new stocks had been added to the Overfished List during that same time (NOAA, 2017). For example, in 2017, NOAA removed six fisheries[7] from the Overfished list and added three other fisheries[8] (NOAA, 2017). The overall trend has been a reduction in the percentage of fisheries on the Overfished List; however, the percentage of fisheries on the Overfishing List (a different list) has remained the same or increased since 2014 (NOAA, 2017).

Globally, collapses in large predatory fish now occur in all large marine ecosystems, primarily due to mismanagement and overfishing (Worm et al., 2007; Costello, Gaines, & Lynham, 2008). Except for the Northwest and Northeast Pacific regions, harvests in temperate areas have declined for several years (FAO, 2018), indicating reduced populations of fish biomass, generally. Models have indicated that by 2050, overfishing and habitat degradation will have depleted not only the oceanic shelves, but also deep slopes, canyons, seamounts, and deep ocean ridges of "bottom fish" such as orange roughy, Chilean seabass, and hagfish (Pauly et al., 2003; Worm et al., 2006). In 2015, the FAO considered 33.1% of fish stocks to be harvested at biologically unsustainable levels (2018). [9]

<u>Focus Question 3</u>. To what extent does the harvesting of wild, native fish exclusively for use as a fertilizer harm the environment?

Based on available data (see Table 1 in *Specific Uses of the Substance*) and as described in *Focus Question #2*, wild, native fish are not harvested exclusively for fertilizer use. Use of wild, native fish that are otherwise unmarketable except as fertilizer (bycatch) can at least prevent them from becoming waste under some circumstances, as can using inedible parts leftover from fish processing (see *Focus Question #8*). These fish are not harvested *exclusively* for use as fertilizer, nor are the fish used in reduction processes (meal, oil and solubles).

While wild, native fish are not harvested exclusively for use as a fertilizer, fish biomass is harvested and incorporated into fish-based fertilizers. Production of fish-based fertilizers could, to a small degree, drive demand for fish harvested for meal, oil, and solubles production. Fish-based fertilizers are unlikely to create demand for fish waste that drives fish harvesting rates for human consumption. The extent that harvesting wild, native fish for use as a fertilizer harms the environment is small compared to the primary uses of fish because of the difference in scale. Due to a lack of information specific to fish-based fertilizer production, the following information briefly describes some of the harm that occurs due to fishing activity generally.

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[6] <u>Overfished</u>: "*A stock having a population size that is too low and jeopardizes the stock's ability to produce its MSY*" (NOAA, 2017).
<u>Overfishing</u>: "*a harvest rate higher than the rate that produces its MSY*" (NOAA, 2017).
<u>Maximum sustainable yield (MSY)</u>: "*The largest long-term average catch that can be taken from a stock under prevailing environmental and fishery considerations*" (NOAA, 2017).

[7] Removed from Overfished List: Pacific Coast Yelloweye Rockfish, Georges Bank Winter Flounder, Gulf of Mexico Gray Triggerfish, Gulf of Mexico Red Snapper, Pacific Ocean Perch, and Western Atlantic Bluefin Tuna.

[8] Added to Overfished List: Southern Atlantic Coast Red Grouper, North Atlantic Shortfin Mako, and Southern Georges Bank / Mid-Atlantic Red Hake.

[9] Fished at biologically unsustainable levels: "*stocks less abundant than the level needed to produce MSY*" (FAO, 2018).

Regardless of the intended use, harvesting wild, native fish can contribute to biodiversity loss, habitat destruction, and loss of ecosystem services. The overall effect of harvest is dependent at least in part on individual species, their ecosystem role, fishery management systems, harvesting methods, the types of associated bycatch, and myriad other factors. Due to the complexity and number of specific factors involved, the response will focus on a few of the most common "non-waste" fish destined for meal, oil, and solubles production, and the effect of fishing on marine ecosystems generally.

Wild fish used in fish meal production

Based on the data presented in *Source or Origin of the Substance*, approximately 55 percent of fish-based fertilizer products approved for use by OMRI contain fish meal (12 percent) or fish solubles (43 percent) (OMRI, 2019a). The majority of fish meal used in fish-based fertilizers is produced from fish waste, but a minor amount (2 percent) is produced from fish caught specifically for reduction purposes (fish meal and fish oil, with fish solubles as a byproduct or coproduct). Fish solubles used in fish-based fertilizers on the other hand most often come from fish harvested specifically for meal and oil production (OMRI, 2019a).

While none of the fish species known to be harvested for fish reduction purposes and which are incorporated into fish-based fertilizer products are threatened or endangered species (see Table 2), their population dynamics are not understood in many cases. It is also difficult to ascertain the effect of removing biomass, even from a sustainable fishery, considering that these species may be a food source for other species. Meal and oil fish can be critical to the function of entire ecosystems; for example, Pacific thread herring (*Opisthonema libertate*) and Pacific anchoveta (*Cetengraulis mysticetus*) are critical links in the Gulf of California, transferring energy through the food web and controlling the organization of these ecosystems (Hernandez-Padilla et al., 2017).

Table 2: Fish species harvested for reduction purposes

Group	Common name	Scientific name	IUCN status+ population trend[10]	Experienced collapse?[11]
anchoveta	Pacific anchoveta	*Cetengraulis mysticetus*	LC + Stable	No
	Peruvian anchoveta	*Engraulis ringens*	LC + **Unknown**	1972; 1983-84[12]
sardine	Indian oil sardine	*Sardinella longiceps*	LC + **Decreasing**	1943; 1994; 2015[13]**
	Pacific sardine	*Sardinops caeruleus; Sardinops sagax caerulea*	LC + **Unknown**	1967; 2015[14]**
herring	Pacific thread herring	*Opisthonema libertate*	LC + Stable	No
	Red-eye round herring	*Etrumeus teres*	LC + **Unknown**	No
menhaden	Atlantic menhaden	*Brevoortia tyrannus*	LC + Increasing	No
	Gulf menhaden	*Brevoortia patronus*	LC + Stable	No

***LC = Least Concern (i.e., not a focus of species conservation).**
**** = years where collapse has occurred as indicated by other authors (regionally or globally) but that are not explicitly stated as global collapses in IUCN or FAO data sheets. IUCN data ends at in 2009 for these species.**

Of the primary meal/oil fish that are likely to be used in fish-based fertilizers, three species have documented large-scale population declines (collapses) within the last 50 years or so (Table 2). In some cases, localized populations have undergone severe declines, but these declines are not always captured within FAO fact sheets and International Union for Conservation of Nature (IUCN) data. For example, the FAO's fact sheet for Indian oil sardine (*Sardinella longiceps*) does not capture collapses and declines shown

[10] Based on the *IUCN Red List of Threatened Species* (IUCN, 2019).
[11] Based on FAO Species Fact Sheets (FAO, 2019a; FAO, 2019b; FAO, 2019c; FAO, 2019d; FAO, 2019e; FAO, 2019f; FAO, 2019g; FAO, 2019h). Declines
[12] Based on Schreiber and Halliday (2013)
[13] Based on Kripa et al. (2018).
[14] Based on Shively (2015).

by Kripa, et al. (2018). Pacific anchoveta experienced collapse in 1947 around the Gulf of Nicoya (Bayliff, 1969), but this is both outside of the data range, and possibly too localized to show up in FAO fact sheets and IUCN data. These declines are not always due exclusively to overfishing, but also due to climate, ocean currents, and food web changes—though the exact mechanisms are not always well understood (Chavez, Bertrand, Guevara-Carrasco, Soler, & Csirke, 2008; Bayliff, 1969; Punt, et al., 2016).

Perhaps the most important fish with regard to meal, oil, and solubles production is the Peruvian anchoveta (*Engraulis ringens*). Up to one third of the raw material for fishmeal comes from this fish (FAO, 2007), which is used for animal feed (both terrestrial and aquatic) and fertilizer (Pauly, et al., 2003). According to the FAO, Peruvian anchoveta have been exploited more than any other fish in world history (FAO, 2019a). In 2017, fishers were only able to capture 46 percent of the allotted quota (1.49 MMT), due to a population composed largely of juvenile fish (Fraser, 2018). According to the IUCN, the Peruvian anchoveta population trend is unknown, and this fish has undergone population collapse in the past due to overfishing and climatic conditions (IUCN, 2019; FAO, 2019a).

Likewise, Pacific sardines (*Sardinops caeruleus*) also experienced a population collapse in 1967 (FAO, 2019h). In 2015, the harvest was just 7 percent of what it was in 2009. The most recent decline in Pacific sardines has been attributed to unfavorable environmental conditions (Punt et al., 2016) and intense fishing pressure (Williams, 2014). The population decline of the Pacific sardine has affected populations of brown pelicans, marbled murrelets, Brandt's cormorants, and sea lions, which rely on the sardines as a food source (Williams, 2014; Spratt, 2016). NOAA, however, does not consider the Pacific sardine overfished as of 2017 (NOAA, 2019c).

Wild fish species contributing to fish waste, bycatch, and mortalities

While 55 percent of fish-based fertilizers currently approved by OMRI contain fish meal or solubles, the remaining 45 percent contain hydrolysates, most of which are produced from fish scraps of wild fish, harvested for human consumption (OMRI, 2019a). These include sardines, salmon (including trout), tuna, shark, carp, cod (including pollock), catfish, and many unknown species. The results of harvesting these species, and potentially any fish caught for human consumption, depend on their unique place in the food web, their specific ecosystems, their management systems (or lack-thereof), harvesting methods, ocean dynamics at that location during a given time period, and many other known and unknown factors. However, declines and collapses of numerous species have been well documented, including the Canadian cod fishery (Botsford, Castilla, & Peterson, 1997); West Coast groundfish[15] (Shaw & Conway, 2007); Peruvian anchoveta (Schreiber & Halliday, 2013); coho, sockeye, chinook, and Atlantic salmon species (USGS, 2019); as well as others. To reiterate, production of fish-based fertilizers is not known to currently drive harvest rates for fish used for human consumption (or related bycatch), and instead provides an outlet for what would otherwise become waste.

Large-scale effects of harvesting wild, native fish

The following is a small selection of effects caused by commercial harvesting of wild, native fish. If in the future, fish are harvested exclusively for use as fertilizer, such practice would likely contribute (to some scale-dependent degree) to the effects below.

Through fishing, humans directly remove 24–35 percent of the primary ocean productivity[16] related to upwelling and the continental shelf (Botsford, Castilla, & Peterson, 1997). Fishing activity, in combination with pollution, infrastructure development, and human settlement, has caused the loss of at least half of the salt marshes, one third of the mangroves, and one fifth (or more) of the coral reefs on the planet (Christensen, Aiken, & Villanueva, 2007). Fishing equipment ("gear") causes damage to the biotic components of the seafloor, including corals, sponges, and seagrasses; and alters abiotic components like boulders, gravel, and sand (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003). Degradation of reefs,

[15] A multi-species fishery that was declared a disaster by federal officials in January of 2000, composed of more than 90 species of rockfish, flatfish, roundfish, sharks, skates, and other fish (Shaw & Conway, 2007; NOAA, 2019d).

[16] Primary productivity: "the amount of light energy converted to chemical energy (organic compounds) by the autotrophs of an ecosystem during a given time period" (Campbell, Reece, & Mitchell, 1999).

seagrasses, oyster beds, etc. negatively effects recruitment of juvenile organisms to populations, protection of prey from predators during critical life stages, and biodiversity (Botsford, Castilla, & Peterson, 1997).

Fishing practices can result in the selection of early maturing, smaller females, a decrease in the average age and size of fish, and a loss of genetic diversity which is important for species resiliency (Christensen, Aiken, & Villanueva, 2007; Botsford, Castilla, & Peterson, 1997; National Research Council, 2006). Overfishing specific groups of fish that have defined roles within the ecosystem can change the overall structure of the ecosystem, as other species move in to fill vacated niches, with potentially undesirable results. For example, in the Caribbean, when overfishing created smaller triggerfish populations, sea urchins filled the ecological niche that the herbivorous fish had occupied. Urchins feed differently, eating not only the seaweeds, but also corals and their carbonate substrate (Hay, 1984). This change resulted in thinner, more fragile reefs. Coral reefs provide shelter for between 600,000 and 9 million species (Plaisance, Caley, Brainard, & Knowlton, 2011).

Fishing has negative effects on innumerable non-fish species as well. For example, by some estimates, green and hawksbill sea turtles numbered from 10–several hundred million individuals before European colonization (National Research Council, 2006). A variety of factors, including commercial harvest of sea turtles and their eggs and the mortality caused by long-line and other fishing gear, have drastically reduced their numbers. Current population estimates are 85,000–90,000 nesting female green sea turtles (Sea Turtle Conservancy, 2019a) and 20,000–23,000 nesting hawksbill females (Sea Turtle Conservancy, 2019b). Additionally, the common practice of discarding dead bycatch back into the oceans can cause increases in the populations of aggressive scavenger birds, which predate other seabird nests (Botsford, Castilla, & Peterson, 1997). This is one specific area where the utilization of bycatch for fertilizer use could have a *potential* positive environmental impact, though no information was found to support this. Many hundreds of thousands of seabirds (or more) end up as bycatch from individual types of fishing gear annually, with estimates likely being underestimated by half (Avery, Aagaard, Burkhalter, & Robinson, 2017; Brothers, Duckworth, Safina, & Gilman, 2010; Martin & Crawford, 2015).

Fisheries develop first for species at high trophic levels (such as large, carnivorous fish). The biomass of top ocean predators (such as marlin, swordfish, and large tuna) has declined to between 65–90 percent of pre-industrial levels (National Research Council, 2006). As these fish become scarce, lower trophic level species are harvested instead, leading to a loss of biodiversity within the ecosystem (Christensen, Aiken, & Villanueva, 2007). This practice is known as "fishing down the food web." Regional biodiversity loss in coastal ecosystems is negatively associated with the number of viable fisheries and nursery habitats (e.g., oyster reefs, seagrass beds, and wetlands) (Worm et al., 2006). It is also associated with a loss of filtration services provided by plants, animals, and wetlands—the loss of which increases instances of algal blooms, oxygen depletion, fish kills, shellfish poisoning, and beach closures (Worm et al., 2006).

<u>Focus Question 4</u>. Do different methods, locations, and/or frequencies of harvest pose different levels of risk?

Yes; fishing gear selection, harvest management, location selection, and harvest pressure all pose different levels of risk. Risks also vary for different species and ecological roles.

Fishing gear

Fishing gear itself has a limited ability to operate selectively, though some technologies exist to help decrease the amount of bycatch. Mobile, less selective fishing gear (such as dredges), which operate lower in the water column tends to cause more physical habitat damage than fishing gear that operates higher in the water column. For example, dredges and bottom trawls cause the most physical damage to fish habitat, and collect substantial bycatch of non-target finfish and shellfish species (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003; Pew Oceans Commission, 2003).

The risks from different kind of fishing gear change, depending on species. Dredges, pots, and traps cause the most shellfish and crab bycatch; bottom trawls, gillnets, and bottom long lines cause the most finfish bycatch; midwater gillnets and pelagic longlines cause high shark bycatch; gillnets cause marine mammal bycatch; and midwater gillnets and pelagic longlines cause seabirds and sea turtle bycatch (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003; Pew Oceans Commission, 2003).

Based on rankings provided by 70 experts (24 fishery management council members, 22 Ocean Studies Board scientists, and 24 members of marine conservation organizations), the most common fishing methods ranked on their negative impacts to fish and fish habitat are:

- High impact: bottom trawls, bottom gillnets, dredges, and midwater gillnets.
- Moderate impact: fishing with pots, traps, pelagic longlines, and bottom longlines.
- Low impact: midwater trawls, purse seines, and hook and line; except that some midwater equipment is used similar to bottom trawl nets and impacts should be considered similarly.

Regardless of method, overexploitation can cause fishery collapses (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003).

Alternative fishing practices can reduce bycatch, such as the "back-down method," which allows dolphins to escape purse seine nets intending to catch yellowfin tuna (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003). Streamers and weighted lines can reduce seabird (such as albatross) bycatch in longline fishing of sablefish, and raised footrope trawls can reduce bycatch in Pacific hake fisheries (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003; Avery, Aagaard, Burkhalter, & Robinson, 2017). Reducing bycatch can increase catch, as predators such as seabirds and sharks can be excluded from taking bait (Chuenpagdee, Morgan, Maxwell, Norse, & Pauly, 2003; Avery, Aagaard, Burkhalter, & Robinson, 2017). Trawl nets fitted with special electrified "benthos release panels," or BRPs, can release small fish and other benthic animals, while retaining fish that would otherwise be lost with standard BRPs (Soetaert, Lenoir, & Verschueren, 2016).

Harvest management and the West Coast groundfish fishery example

Fisheries are often managed under some form of "use rights" approach, where a responsible government agency sets a limit on the amount of fish that can be harvested. Some use total allowable catches (TAC) without assigning rights to individual fishers. This encourages individual harvesters to "race to fish" and outcompete other harvesters because the first to harvest the fish can reap the largest economic gain, at least over the short term. Political pressure then leads to larger and larger TACs (Aranda, Murillas, & Motos, 2006).

By contrast, other fisheries are managed under a market-based system where individual fishers are given rights to collect pre-determined quantity of fish, but the methods and timing are self (or market) determined (Miller & Deacon, 2017). These catch share systems[17] can lead to improved fish stocks and higher economic outcomes for fishers (Miller & Deacon, 2017). Out of 11,135 commercial fisheries globally, 121 were managed using catch shares as of 2003. Fisheries using catch shares (or derivatives of) collapsed half as often as fisheries not using catch shares (Costello, Gaines, & Lynham, 2008).

As an example, the West Coast groundfish fishery was declared an economic disaster in 2000 due to severe declines in fish populations caused by overfishing and changes in fish migration that resulted from el Niño-Southern Oscillation Events (Miller & Deacon, 2017; Shaw & Conway, 2007). Under a catch-share management system, bycatch declined in West Coast groundfish fisheries, resulting in the recovery of several species, including widow rockfish, canary rockfish, and Petrale sole (Miller & Deacon, 2017). In order to avoid catches of overfished species, trawlers adopted a variety of approaches: avoiding areas known to have overfished species; shifting to harvesting at night when species segregate into different portions of the water column; shortening the length of time that nets are towed; switching to using traps and hook-and-line; and sharing information amongst fishing association members (Miller & Deacon, 2017). Furthermore, NOAA regulators required on-board monitoring to make sure that fishers were not discarding catches of overfished species. Fish that are caught, and then discarded back to the ocean often do not survive. These market-based approaches were more successful at reducing catches of overfished

[17] Catch shares are a rights-based management technique related to individual transferable quotas (ITQs), whereby the total catch for a fishery is scientifically determined, and a dedicated share is allocated to fishers, communities, and cooperatives. Share values increase as fisheries are better managed (Costello, Gaines, & Lynham, 2008).

species than prescriptive approaches such as fishing closures, gear limitations, and harvest caps applied to entire fisheries (as opposed to individual fishers) that incentivized fishers to "race-to-fish."

Fishing location and timing

Ocean productivity and resiliency to the effects of fishing vary by location. Coll, et al. (2008) developed a metric for estimating the sustainability of fishing in different large marine ecosystems. The areas with the lowest sustainability were the Sea of Japan, West Greenland Shelf, Norwegian Shelf, North Sea, Northeastern U.S. continental shelf, Faroe Plateau, Iceland Shelf, Yellow Sea, Sulu-Celebes Sea, Gulf of Mexico, and the seas around China (Coll, Libralato, Tudela, Palomera, & Pranovi, 2008). Wave stress, tidal velocity, and proximity to areas with large populations of invertebrates can affect the recovery time of an area that has experienced bottom fishing techniques such as dredging (Lambert, Jennings, Kaiser, Davies, & Hiddink, 2014).

Specific types of ecosystems can be both more important for ocean biodiversity and more sensitive to the effects of fishing. For example, coral reefs support high species richness (number of different species) and a large number of ecological functions. At the highest trophic level, coral reefs support numerous species of piscivorous fish that all perform a similar ecosystem function—preying on other fish. The reefs are therefore resilient to a decrease in the abundance of any one of these species caused by fishing. (Ley, Halliday, Tobin, Garrett, & Gribble, 2002). However, many lower trophic level fish species perform other ecosystem functions that are unique—not replicated by any other species. The reefs are thus more vulnerable to the effects of fishing these species, as changes in their populations can alter the ecosystem in significant ways (D'agata et al., 2016). For example, herbivorous fish graze on macroalgae that would otherwise compete for space and resources with corals. When populations of these herbivores are diminished through fishing, the corals are outcompeted and reduced in population by macroalgae in some cases (Hixon, 2015).

The effects of fishing pressure on any given location can vary greatly depending on a variety of factors. For example, populations of small ocean fish such as anchoveta, capelin, sand eel, and Norway pout can fluctuate sharply from year to year due to El Niño-Southern Oscillation events. Additional depletion of these stocks from over-fishing can exacerbate negative effects on species that rely on these smaller ocean fish, including cod, marine mammals, and seabirds (Naylor et al., 2001).

One set of management tools to help relieve pressure on specific fisheries and ecosystems is based around closing access to specific locations. Fishing reserves and fishing closures can be used to recover lost biodiversity and improve productivity around reserves (Worm et al., 2006; Pew Oceans Commission, 2003; Ley, Halliday, Tobin, Garrett, & Gribble, 2002; Costello, 2014). Animal behaviors within reserves can change in positive ways; for example, fish and lobster populations increase at a rate faster than expected outside the reserve (with all else being equal) (Costello, 2014). Marine reserves can also serve as "controls," or regions that can be compared to actively fished areas, allowing scientists to better understand human impacts on different ecosystems (Costello, 2014).

Focus Question 5. Are there any species of wild, native fish for which there are no environmental impacts of harvest?

Information suggesting that there are no environmental impacts from the harvest of certain species of wild, native fish was not found.

In at least one case, harvest of native fish can benefit other, commercially desirable native species. Northern pikeminnow (*Ptychocheilus oregonensis*) are predators of juvenile salmonids, and both are native to the Columbia River basin. While the northern pikeminnow has thrived since the introduction of hydroelectric dams, wild salmonid populations have decreased. Through the Pacific States Marine Fisheries Commission, northern pikeminnow populations have been managed in an effort to control predation on salmonid populations. Northern pikeminnow are captured under a bounty program, frozen, and later used to produce feed and fertilizer ingredients (Radtke, Carter, & Davis, 2004).

Focus Question 6. Are there any fish fertilizer products derived from farmed fish, and if so, are there any environmental impacts?

Some fish fertilizer products are derived from farmed fish, but these fish are initially raised for human consumption, and the fertilizers are manufactured from the byproducts of either fish waste or mortalities. Therefore, some of the environmental impacts of using this material may be positive. Of the products listed by OMRI, 14.5 percent are known to be derived either partially or entirely from farmed fish. Farmed fish species used in fertilizers include channel catfish, rainbow trout, salmon, tilapia, and carp (OMRI, 2019a). The information available does not show fish-based fertilizer production at the current time drives farmed fish demand. If farmed fish (instead of farmed fish byproducts) were used directly in fish-based fertilizers, then such production could contribute to the issues described in the following sections.

Growth of aquaculture

Aquaculture production has increased dramatically within the last few decades. In 2016, aquaculture generated 80 MMT of fish (nearly 47 percent of total fish production), with China responsible for more than 61 percent of aquaculture production (FAO, 2016). The United States is 16th in aquaculture production, with 0.44 MMT in 2016 (FAO, 2016). The five most common fin fish farmed are *Ctenopharyngodon idellus* (grass carp), *Hypophthalmichthys molitrix* (silver carp), *Cyprinus carpio* (common carp), *Oreochromis niloticus* (Nile tilapia), and *Hypophthalmichthys nobilis* (bighead carp) (FAO, 2016). While the perception of aquaculture is that it relieves harvesting pressure on wild fish, some aquaculture practices instead contribute to the decline of wild fish stocks. Feeding, housing, and maintaining farmed fish all create environmental impacts.

Impacts of feeding farmed fish

At least 220 species of finfish and shellfish are farmed worldwide (Naylor et al., 2001). Fish can be contained in ponds, tanks, and cages (including floating net cages). Marine and anadromous fish (those that migrate between marine and freshwater environments) are typically fed using formulated feeds, while freshwater species like carp and catfish can be grown in ponds, which may or may not be fed formulated feed (Naylor et al., 2001). Crop wastes and other nutrient rich materials may be used in "extensive"[18] or "traditional" aquaculture to provide nutrients for algae and other fish food organisms (Naylor et al., 2001). Formulated feeds for herbivorous and omnivorous fish can contain soybean, cottonseed, and peanut meals as well as protein obtained from fish and terrestrial animals. Formulated feeds for carnivorous fish are composed of large proportions of fish meal and fish oil, which include the essential amino acids lysine and methionine (Naylor et al., 2001).

Aquaculture of some fish species results in a loss of overall trophic efficiency (Christensen, Aiken, & Villanueva, 2007). In many cases, aquaculture emphasizes farming high-trophic level species. For every kilogram of shrimp, salmon, cod, seabass, and tuna, 2–5 kg of wild-caught fish is used in feeds used in their production (Naylor et al., 2001). Some aquaculture operations are stocked using wild-caught fish. Additionally, aquaculture operations have caused the destruction of mangrove forests and coastal wetlands, introduced fish diseases, and introduced non-native fish that can hybridize with wild, native fish (Naylor et al., 2001). Omnivorous fish require less wild-caught fish for food than carnivorous species, but their food is sometimes supplemented with fish oil or fish meal from wild-caught stocks (Naylor et al., 2001). Aquaculture production does increase global aquatic animal supplies, but mostly because of the contributions of carp, mollusks such as oysters, mussels, and clams, and other primarily herbivorous species (Naylor et al., 2001).

While fish have similar dietary protein requirements, herbivorous fish are able to more efficiently use plant-based protein than carnivorous fish, requiring less fish meal and fish oil to supply essential amino acids (Naylor et al., 2001). Per kilogram produced, catfish, carp, and milkfish require less fish-based feed

[18] Extensive or traditional fish farming is based primarily on using the natural productivity of the ecosystem to provide energy and nutrients for fish. This is in contrast to intensive fish farming, where a higher density of fish are raised by controlling production conditions, including supplying nutrients, and actively controlling water quality within the production environment (Lucas & Southgate, 2012).

inputs than what the aquaculture operations produce (a net gain of fish by weight); other commonly farmed fish require more fish-based inputs than the amount of product they produce (Naylor et al., 2001).

Impacts of fish farm infrastructure, waste, and escaped fish

While aquaculture feeds highlight the issue of trophic inefficiency, this concern is present in harvests of wild fish as well. Other issues are unique to aquaculture production. For example, fish farms produce nutrients, waste, and drugs (such as antibiotics) that can disrupt native ecosystems (Naylor et al., 2001). Wastes including uneaten food particles, fecal pellets, and ammonia and nitrites near fish pens disrupt the nutrient cycles of surrounding ecosystems and create toxic conditions for other species (Naylor et al., 2001). Between 1996 and 2013, at least 20 different types of antibiotics were reportedly[19] used in Chinese aquaculture; some of which were originally intended for human use only, and whose application in aquaculture may contribute to bacterial resistance in human medication (Liu, Steele, & Meng, 2017).

Fish farms raising species such as milkfish, tuna, shrimp, and eels may rely heavily on wild-captured fry as opposed to hatchery-raised. During the process of collection, large amounts of bycatch (up to 85 percent) is produced that may be discarded without further use. To collect 1.7 billion milkfish fry for ponds in the Philippines, 10 billion fry of other fish species were destroyed; fry bycatch in three collecting centers in India was estimated at 62 million–2.6 billion fish per annum (Naylor et al., 2001).

Infrastructure (e.g., buildings, pens) for fish farms can cause damage to coastal environments through displacement and pollution. These locations can be important for both aquatic and terrestrial species (e.g., birds, reptiles and mammals) as well as sensitive to damage (Islam & Wahab, 2005). Milkfish and shrimp ponds have resulted in the loss of hundreds of thousands of hectares of mangrove forests and coastal wetlands (Naylor et al., 2001). These habitats are used as nurseries for aquatic animals and serve other ecological functions, such as offering protection from storms, flood control, and water filtration that helps prevent contamination of adjacent ecosystems such as coral reefs, which themselves include important fisheries. Mangrove forests provide critical habitat for young fish that later move farther out to sea, becoming parts of offshore fisheries. The effects are not exclusively environmental; humans that rely on the productivity of the mangrove forests for their livelihood lose access as aquacultural developments privatize the productivity and resources that were formerly common property (Naylor et al., 2001; Christensen, Aiken, & Villanueva, 2007).

Farmed fish may not be native to the ecosystems where they are farmed. Farmed Atlantic salmon commonly escape from their pens; in some places, up to 40 percent of the salmon harvested from natural habitats were of farmed origins. Escaped fish of farmed origin may hybridize with wild fish, alter the genetic makeup of these populations, and spread pathogens such as the salmon fluke, *Gyrodactylus salaris* (Naylor et al., 2001).

Focus Question 7. Are there any fish fertilizer products derived from wild, *non-native* fish populations, and if so, are there any environmental impacts?

There is a small number of fish fertilizer products derived from wild, non-native fish populations, but it is unclear whether some of these are currently produced or were ever produced beyond trial runs. All of the fertilizers identified were based on non-native carp species. In 2015, the Missouri Agriculture and Small Business Development Authority awarded Heartland Harvest Naturals, LLC a grant for a marketing study on a commercial Asian carp[20]-based liquid fertilizer[21] (MDA, 2015). A 2018 report contracted by the Illinois Department of Natural Resources (IDNR) references St. Andrew's Holy Carp! fertilizer as a fish-based fertilizer (Tetra Tech, 2018). The company maintains social media that references working with IDNR to

[19] While 20 were reported, 32 were detected in Chinese aquatic products (Liu, Steele, & Meng, 2017).

[20] Asian carp encompass silver (*Hypophthalmichthys molitrix*), bighead (*H. nobilis*), grass (*Ctenopharyngodon idella*), and black carp (*Mylopharyngodon piceus*) species (Phelps et al., 2017).

[21] While the product could not be found online, Heartland Harvest Naturals, LLC was issued a permit to sell commercial fertilizers in 2017 (University of Missouri-Columbia, 2017). It is not clear if the company produced a commercial Asian carp-based liquid fertilizer or were only engaged in market research.

produce a fertilizer to dispose of invasive Asian carp fish from rivers (Hochderffer, 2018), but no method to purchase the product was found.

Schafer Fisheries is also referenced in the IDNR report as an Asian carp processor that produces fish-based fertilizers (Tetra Tech, 2018). Schafer Fisheries websites indicate that they process a variety of non-native carp species sourced from commercial fishers, and they produce two OMRI Listed fish hydrolysate products from fish scraps (Schafer Fisheries, 2018; SF Organics, no date; OMRI, 2019b).

No information was found that documented a link between impacts to the environment and production of fertilizer from wild, non-native fish. Production of fish fertilizer is often incidental to fish harvest—an outlet for fish waste that is otherwise discarded. A report contracted and published by the Illinois Department of Natural Resources included a recommendation to market wild, non-native fish such as Asian carp as a fertilizer in order to incentivize their capture (Tetra Tech, 2018).

According to Phelps et al. (2017), a complete understanding of environmental perturbations caused by Asian carp is limited. Silver carp themselves were introduced as a biological control measure to improve water quality on fish farms by eating plankton but escaped during flood events in the 1970s. When present in large numbers, silver carp are likely responsible for declines in native fish such as gizzard shad (*Dorosoma cepedianum*) and bigmouth buffalo (*Ictiobus cyprinellus*) (Phelps et al., 2017). Ostensibly, if enough silver carp were harvested to remove pressure on native fish, then some environmental impact might be observed; however, Asian carp species are currently continuing to expand in states like Illinois, despite an average annual harvest rate of almost 2,722 MT (Tetra Tech, 2018).

See *Focus Question #5* for a related discussion of a native fish, northern pikeminnow, used as a source of protein in fertilizer.

<u>Focus Question 8</u>. Please describe the environmental impact of using wild, native fish harvested exclusively for fertilizer versus using byproducts or invasive species.

As described in *Specific Uses of the Substance*, and *Focus Questions #2* and *#3*, wild, native fish are not known to be commercially harvested *exclusively* for fertilizer use at this time. As such, available data indicates that all fish-based fertilizers are produced from either fish waste; bycatch; or as a byproduct/coproduct of fish meal, oil, and solubles manufacturing. Wild, native fish are used in fertilizer production, as are farmed fish; however, their inclusion in fertilizers is likely either benign or in some cases *potentially* having some environmentally positive effects. Market forces may limit the likelihood that fish are ever harvested exclusively for fertilizer use, as fish products for human consumption have higher value (Kim, 2014).

It is not clear that the utilization of fish waste, bycatch, and byproducts for fertilizer use has a significantly positive effect on the environment either, especially if one considers the energy inputs and relatively small scale of fish fertilizer production. Modern industrial fisheries often directly consume substantially more energy than exists nutritionally within the caught animals themselves (Tyedmers, 2004). Transportation and conversion of these fish products into fertilizers likely adds additional energy costs to these materials. No information was found that demonstrated that energetically, manufacturing fish-based fertilizers from fish waste and other byproducts improved the energy efficiency of fishing activity.

Perhaps the most likely place where using fish waste/byproducts for fertilizers can theoretically offer a tangible environmental benefit (beyond the soil fertility aspect) is associated with disposal. Currently, disposal of fish waste and other byproducts creates environmental problems due to a lack of suitable options (Kim, 2014).

Utilization of fish carcass waste

Large amounts of waste are produced from industrial fish processing, and these wastes are disposed of in landfills, incinerators, waterways, and on land (Dao & Kim, 2011; Naylor, et al., 2001; Aranganathan & Rajasree, 2016; Dominy, Sato, Ju, & Mitsuyasu, 2014; Kim, 2014). These include the head, gills, fish frame, viscera, scales and skin (Kim, 2014). For example, up to 70 percent of a processed tuna fish ends up as waste, generating 450,000 metric tons of waste material per year. These wastes are economically and environmentally costly to dispose of; disposed fish can attract insect pests, produce toxic gases and offensive odors, and contaminate the environment (Aranganathan & Rajasree, 2016). Some wastes are converted into other materials, such as fishmeal, fish oil, and fertilizers (Illera-Vives, Labandeira, Brito, & López-Fabal, 2015; Aung & Flick, 1982; Naylor, et al., 2001). Utilizing otherwise wasted bycatch and fish by-products as a raw material for agricultural fertilizers has been suggested as a strategy to reduce wastefulness and improve crop production (Aranganathan & Rajasree, 2016).

Utilization of fish press water (stickwater)

As of the early 1980s, most fish press water[22] or fish wash water containing fish soluble nutrients was obtained as waste by-products of the menhaden and tuna fisheries (Aung & Flick, 1982). Roughly 900,000 metric tons of stick and wash water were produced from the tuna, anchovy, and menhaden fisheries in the United States in 1977 (Aung et al., 1984). Producers in the U.S. were prohibited from discharging these wastes overboard or into most municipal sewage plants, and so the Virginia seafood industry requested assistance with this issue from Virginia Tech in 1977 (Aung et al., 1984). The alliance developed a proposal for converting these fish press water and wash water wastes into fish soluble nutrients (solubles) as an agricultural fertilizer (Aung et al., 1984).

Utilization of bycatch

Due to the limited selectivity inherent in many fishing processes, non-target fish (bycatch) are often harvested along with fish of interest. Domestically, bycatch is 16–32 percent of the total catch (Love, Fry, Milli, & Neff, 2015; Pauly, et al., 2003). During the 1990s, the volume of discarded (by-catch) fish was approximately 16-40 MMT (Watson & Pauly, 2001). It may not always be ecologically sensitive to return all bycatch back to the ocean because such discarded fish often do not survive (Miller & Deacon, 2017). While fish are generally harvested for human consumption, some bycatch is not allowed to enter the market for such use, or may be otherwise undesirable for human consumption (European Commission, n.d.; Aranganathan & Rajasree, 2016). Instead, these fish are diverted to other non-human food uses (such as fertilizers) to avoid wasting the fish. The intent in some cases is to provide an outlet for the bycatch such that it is not wasted, while minimizing incentives to create an economically valuable co-product from bycatch species.

For example, European Union (EU) fisheries are managed under a quota system whereby the weight of fish that can be caught has pre-determined limits, with bycatch weight included (European Commission, n.d.). Once the allowed quota is harvested, that fishery must be closed. Beginning in 2014, the EU phased in requirements where all fish (regardless of species, size, quality, etc.) that are caught must be counted towards the allowed quota (with exceptions[23]) in an attempt to encourage more selective harvesting practices. To avoid creating unnecessary waste, fish outside of size or other requirements may be sold, but not for human consumption. Responsibility for finding outlets for non-marketable (for non-human consumption) fish falls on EU Member States, but with the obligation of not creating an economically valuable market for such fish that could incentivize their capture (European Commission, n.d.). Seemingly in contrast to the European model, NOAA provides funding opportunities to specifically develop markets for low value bycatch species in the United States (NOAA, 2019b).

See *Focus Question #7* for a discussion of the effects of using invasive Asian carp for fish-based fertilizers.

Report Authorship

The following individuals were involved in research, data collection, writing, editing, and/or final approval of this report:

[22] Fish press water is the remaining liquid after the steam extraction of oils from fish. It is often mixed with wash or bilge water, containing fish blood, residual oil, and fish fragments (Aung L. , et al., 1984).

[23] Some species may not be harvested ("prohibited" species, such as basking sharks), and these animals must be returned to the water.

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All individuals are in compliance with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

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