Rapidly Increasing Plastic Pollution from Aquaculture Threatens Marine Life

Charles Moore*

I. INTRODUCTION

> "It is impossible to make a complete list of the environmental impacts of the current human population, a population that is a thousand-fold larger than the mean population of other similar-sized mammals. One set of influences has involved our use of the seas for food . . . ."[1]

World seafood production, not including plants, is near 150 million tons annually,[2] which is a little more than half of the world's annual plastic production.[3] World aquaculture production, the practice of farming fish, attained an all-time high in 2010 of 60 million tons, roughly 40% of the seafood produced in 2010.[4] About 600 aquatic

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 In 1994, Captain Charles Moore founded the Algalita Marine Research Institute. In 1995, he launched his aluminum-hulled research vessel, ALGUITA, in Hobart, Tasmania. Since then, he has logged over 100,000 miles of research voyages aboard this vessel. His 1999 study shocked the scientific world when it found six times more plastic fragments by weight in the surface waters of the Central Pacific than zooplankton. His second paper found that plastic outweighs zooplankton by a factor of 2.5 in the surface waters of Southern California.

1. *See* Charles W. Fowler, *Ecological Effects of Marine Debris: The Example of Northern Fur Seals*, *in* PROCEEDINGS OF THE INTERNATIONAL MARINE DEBRIS CONFERENCE ON DERELICT FISHING GEAR AND THE OCEAN ENVIRONMENT 40, 40 (2000), *available at* http://hawaiihumpbackwhale.noaa.gov/documents/pdfs_conferences/proceedings.pdf.

2. FISHERIES & AQUACULTURE DEP'T, FOOD & AGRIC. ORG. OF U.N., THE STATE OF WORLD FISHERIES AND AQUACULTURE 3 (2012) [hereinafter FAO FISHERIES & AQUACULTURE DEP'T], *available at* http://www.fao.org/docrep/016/i2727e/i2727e.pdf.

3. *See Plastics—The Facts 2012: An Analysis of European Plastics Production, Demand and Recovery for 2011*, PLASTICSEUROPE 6 fig.2 (2012), http://www.plasticseurope.org/Document/plastic-the-facts-2012.aspx?Fo1ID=2.

4. FAO FISHERIES & AQUACULTURE DEP'T, *supra* note 2, at 24.

species are raised in captivity in around 190 countries and territories.[5] While global capture fisheries production has remained stable at 90 million tons annually,[6] aquaculture is a fast-growing animal-food-producing sector and may lead to seafood consumption exceeding beef, pork, or poultry in this decade.

Freshwater fishes dominate global aquaculture production at 33.7 million tons annually, while diadromous fishes (living in both fresh and saltwater during their lifetimes) and marine fishes at a combined 5.4 million tons are at the bottom, less than either mollusks or crustaceans.[7] As space limitations force aquaculture grow-out facilities into wetlands, mangroves, embayments, and the open ocean, the operators' need for floating and submerged containment and substrate infrastructure often results in routine and experimental use of plastics. Escaped plastics from these facilities are increasingly being encountered in studies of bays, beaches, and the ocean. Many aquaculture facilities are located away from population centers and consequently encounter minimal "not in my back yard" (NIMBY) pressures, which arise from impaired recreation or viewscapes, changes in habitat, or from lost gear on beaches.

Lost gear from fishing and aquaculture is not monitored or regulated, even though most seafood production, including wild-harvested and farmed, predominantly occurs near coasts. Knowledge of the amount of plastic farming and fishing gear lost is important because the marine food web at every trophic level is being displaced by plastics that mimic natural food sources. In addition to being nonnutritive and nondigestible, plastics transport toxic chemicals used in manufacturing processes and absorbed from seawater.[8] When these vagrant plastics mimic food and are ingested by sea life, they cause effects that include stomach blocking and laceration, starvation, and liver deterioration, including cancer.[9]

This Article will discuss the types of plastic equipment lost in the marine environment from aquaculture. It will also propose measures to remedy the deleterious effects of the lost plastic. In order to be sustainable, aquaculture operations will have to use nontoxic materials

5. *Id.* at 25.
6. *Id.* at 6.
7. *Id.* at 10.
8. Chelsea M. Rochman et al., *Ingested Plastic Transfers Hazardous Chemicals to Fish and Induces Hepatic Stress*, 3 SCI. REP., art. no. 3263, 2013, at 3, *available at* http://www.nature.com/srep/2013/131121/srep03263/pdf/srep03263.pdf.
9. *See generally id.*; Charles James Moore, *Synthetic Polymers in the Marine Environment: A Rapidly Increasing, Long Term Threat*, 108 ENVTL. RES. 131, 134-35 (2008).

and prevent equipment loss.[10] In order to prevent damage to marine habitats from aquaculture, norms and regulations requiring monitoring, reporting, and controlling equipment loss should be created and promulgated by regulatory agencies and certification associations. Successfully sustainable aquaculture lies in benign design that results in minimal disruption, pollution, or degradation of the environment surrounding seafood-culturing operations.

II. BACKGROUND

Aquaculture, as well as intensive ocean fishing, began in Europe around a thousand years ago when anadromous species, which leave rivers and mature at sea, and fish living in lakes and ponds failed to meet the needs of European populations.[11] At the end of the first millennium, "Christian prohibitions against eating meat from quadrupeds on certain days fueled a growing demand for fish. Benedictine philosophy held that fish were less 'fleshy' than other animals and so less likely to incite sexual passion."[12] Between 130 and 150 "fish-eating days" per year were observed by different denominations.[13] It was during the medieval period of rapid population growth that the practice of culturing fish in ponds, known as aquaculture, was invented in France and spread rapidly.[14] Intensive ocean fishing developed as well, and by 1376, the trawling of nets in coastal waters had become onerous to some who petitioned English King Edward III to ban them.[15]

The equipment used for both aquaculture and capture fishing up until the 1960s consisted of metal, wood, and natural fibers, which would

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10. *Cf.* Rochman et al., *supra* note 8, at 5 (noting if we continue our current practices, plastic waste is predicted to reach 2.2 billion tons annually by 2025).

11. CALLUM ROBERTS, THE UNNATURAL HISTORY OF THE SEA 18, 25-26 (2007).

12. *Id.* at 19.

13. *Id.*

14. *Id.* at 25.

15. *Id.* at 131-32 ("The commons petition the King, complaining that where in creeks and havens of the sea there used to be plenteous fishing, to the profit of the Kingdom, certain fishermen for several years past have subtily contrived an instrument called 'wondyrechaun' made in the manner of an oyster dredge, but which is considerably longer, upon which instrument is attached a net so close meshed that no fish be it ever so small which enters therein can escape, but must stay and be taken. And that the great and long iron of the wondyrechaun runs so heavily and hardly over the ground when fishing that it destroys the flowers of the land below water there, and also the spat of oysters, mussels and other fish upon which the great fish are accustomed to be fed and nourished. By which instrument in many places, the fishermen take such quantity of small fish that they do not know what to do with them; and that they feed and fat their pigs with them, to the great damage of the commons of the realm and the destruction of the fisheries, and they pray for a remedy." (quoting G.L. ALWARD, THE SEA FISHERIES OF GREAT BRITAIN AND IRELAND (1932))).

readily undergo oxidative decay and/or biodegrade in aquatic environments.[16] The plastic age ushered in materials so resistant to natural decay that lost plastic aquaculture gear can last for centuries. Plastic exposed to sunlight becomes embrittled, principally through photodegradation and the leaching of monomeric conditioning agents into the surrounding water, and eventually breaks into bite-sized bits that last far longer than natural materials.[17] Bits of plastic have been found in three important species of catfish and two species of drum,[18] all commonly raised in aquaculture operations. Miscellaneous fragments of plastic were found in 35% of common planktivorous fish.[19] Ingested plastics can transfer hazardous chemicals to fish and induce liver disease. The direct impacts on "[f]ish, one of the largest and most diverse groups of animals and of great ecological—and commercial—importance, are useful as sensitive indicators of effects associated with stressors in aquatic habitats."[20] "Most plastic goods . . . have no detectable aroma, but by tangling, snaring, or choking birds, fish, seals, dolphins, and even whales, their indirect impact can be powerful. They bring to the sea the smell of death."[21] Another deleterious effect posed by vagrant ocean plastics is that they transport species to foreign habitats.[22]

Evidence from remote beaches and the high seas implicates aquaculture as a significant contributor to the ocean's plastic load.[23] The rapid expansion of the aquaculture industry has not been accompanied by a corresponding attention to the consequences of equipment loss, especially equipment made from plastics, and no regulatory remedies have been created.

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16. *See* Dep't of Fisheries & Oceans, Gov't of Can., *Marine Debris Trashing Our Oceans: Trashing Our Future*, EAST COAST TRAIL ASSOC., http://eastcoasttrail.ca/pdf/4_marine%20debris.pdf (last visited Feb. 23, 2014).

17. *See* Moore, *supra* note 9, at 131-32.

18. David V. Dantas et al., *The Seasonal and Spatial Patterns of Ingestion of Polyfilament Nylon Fragments by Estuarine Drums (Sciaenidae)*, 19 ENVTL. SCI. & POLLUTION RES. 600, 602 (2012); Fernanda E. Possatto et al., *Plastic Debris Ingestion by Marine Catfish: An Unexpected Fisheries Impact*, 62 MARINE POLLUTION BULL. 1098, 1099-1100 (2011).

19. Christiana M. Boerger et al., *Plastic Ingestion by Planktivorous Fishes in the North Pacific Central Gyre*, 60 MARINE POLLUTION BULL. 2275, 2276 (2010).

20. Rochman et al., *supra* note 8, at 1-2 (footnotes omitted).

21. SYLVIA ALICE EARLE, SEA CHANGE: A MESSAGE OF THE OCEANS 247 (1995).

22. *See* David K.A. Barnes, *Invasions by Marine Life on Plastic Debris*, 416 NATURE 808, 808 (2002).

23. *See generally* Moore, *supra* note 9.

III. INDUSTRIAL AQUACULTURE

Approximately one-fourth of all aquaculture is devoted to growing mollusks, with the major species being oysters, mussels, and clams.[24] Typical grow-out methods for oysters are described in both commercial and government publications and include the following: (1) laying small oysters onto empty mature oyster shells and putting them directly on the bottom in the intertidal zone in relatively calm bays and estuaries, (2) putting the mature shells in bags or satchels that are placed on the bottom, suspended from stakes driven into the bottom, or hung from floats or docks, and (3) longline installations in which rope is strung between floats or stakes and mature shells are evenly spaced by putting short lengths of tubing between them.[25] A Washington State publication, *Small-Scale Oyster Farming for Pleasure and Profit in Washington*, describes these methods, indicating types of plastic that can be used for bags, lines, and spacers (polyethylene and polypropylene); however, no mention is made of equipment loss, only loss of oysters due to predation and rough weather.[26] When rough weather causes loss of oysters, it often also causes loss of the gear used to grow them. The spacers used in longline aquaculture of oysters in Asia are one of the most common identifiable debris items found on Hawaiian beaches and samples taken from the North Pacific Gyre.[27] The Washington publication summarizes legal aspects of oyster aquaculture in Washington:

> In April 1985, the Washington State Legislature declared aquaculture to be an agricultural endeavor, placing it under laws that apply to the advancement, benefit or protection of the agriculture industry. The Legislature further declared the Department of Agriculture to be the lead agency in all aquacultural matters. Currently, this agency provides a supportive framework and general marketing and promotional assistance for all aquaculture activities and products. However, issuing most licenses and permits is the responsibility of other agencies.[28]

Nowhere in this publication is the issue of loss of persistent plastic equipment addressed.[29] Because monitoring of equipment loss or marking of equipment is not required, the only information on losses is

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24. FAO FISHERIES & AQUACULTURE DEP'T, *supra* note 2, at 36, 39 fig.10.
25. *Farming Oysters*, PENN COVE SHELLFISH, http://www.penncoveshellfish.com/Farming/farm_oysters.html (last visited Jan. 19, 2014); WASH. SEA GRANT, WSG-AS 0203, SMALL-SCALE OYSTER FARMING FOR PLEASURE AND PROFIT IN WASHINGTON 7-11 (2002), *available at* http://wsg.washington.edu/mas/pdfs/smallscaleoysterlr.pdf.
26. *See* WASH. SEA GRANT, *supra* note 25, at 8-11.
27. Charles J. Moore, unpublished research (on file with author).
28. WASH. SEA GRANT, *supra* note 25, at 12.
29. *See id.*

from informal beach cleanups, which cannot trace the equipment to the permittee responsible.

Certification organizations, with dozens of pages of standards, fail to mention escaped aquaculture gear. For example, the Food and Agriculture Organization of the United Nations' *Technical Guidelines on Aquaculture Certification* in paragraph 51, the only paragraph with any relevance to this issue, under "Minimum Substantive Criteria for Addressing Environmental Integrity in Aquaculture Certification Schemes," states in nearly meaningless general terms, "Infrastructure construction and waste disposal should be conducted responsibly."[30] And the Global Aquaculture Alliance, which provides guidance to organizations granting certification to individual operations, refers in its section on standards for finfish and crustaceans only to "[h]ousehold trash and other farm wastes" (not the grow-out infrastructure), which should "not be dumped in mangrove areas, wetlands or other vacant land and shall be removed promptly and properly to avoid accumulation."[31] Apparently accidental loss is an accident for which no responsibility needs to be borne by the operators.

Unfortunately, accidental loss is no accident. It is a necessary component of a system that rewards "innovation," which is practically exempted from review under Washington State's Administrative Code.[32] As an example, thick polyvinyl chloride (PVC) tubes, the diameter of a fist and the length of a forearm, are used in the culture of geoduck clams in Puget Sound. The PVC tubes surround the young clams in the intertidal habitat until they reach a size where predation is minimal, in approximately two years.[33] These PVC tubes are lost in significant numbers due to natural scouring forces, storm events, and collisions with boaters who don't see them at high tide. The PVC tubes are heavier than seawater and migrate to the bottom of the Sound or are rolled by waves and washed onto the shore. This form of aquaculture is promoted by the state of Washington, which leases some state lands to private aquaculture operators.

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30. *Technical Guidelines on Aquaculture Certification*, FISHERIES & AQUACULTURE DEP'T, FOOD & AGRIC. ORG. OF U.N. 14-15 (2011), http://www.fao.org/docrep/015/i2296t/i2296t00.htm.

31. *Finfish and Crustacean Farms: BAP Standards, Guidelines*, GLOBAL AQUACULTURE ALLIANCE 22 (2013), http://www.gaalliance.org/cmsAdmin/uploads/bap-fishcrustf-413.pdf.

32. *See* WASH. ADMIN. CODE § 173-26-241(3)(b)(i)(B) (2011) ("The technology associated with some forms of present-day aquaculture is still in its formative stages and experimental. Local shoreline master programs should therefore recognize the necessity for some latitude in the development of this use as well as its potential impact on existing uses and natural systems.").

33. *See Geoduck Aquaculture*, WASH. SEA GRANT SEA STAR, Summer 2007, at 2, *available at* http://www.wsg.washington.edu/communications/seastar/archive/Summer07.pdf.

In an effort to minimize the cost of the protective PVC tubes, one such operator "innovated" by substituting PVC tubes with lightweight, clear polystyrene cups, the type used to serve drinks on airlines, with the bottoms cut out. As many people who have used these cups know, they are brittle, crack easily, and are extremely light weight. This ill-conceived experiment used 40,000 polystyrene cups per acre and resulted in a huge spike in the loss of aquaculture gear, evidenced by cups washing up to the shore and littering the bottom of the Sound.[34]

Plastics are used in other types of aquaculture. Invertebrates, such as sea urchins, are farmed in massive arrays of buoys and bags in the nearshore waters of Korea.[35] These green glass or black plastic buoys are the most common buoys found in the North Pacific Gyre and also litter the beaches of Korea near the aquaculture farms.

IV. Fish Aggregation Devices

Mention should be made of the plastics used in an intermediate form of seafood production, namely the facilitation of wild capture fisheries by the deployment of fish aggregation devices (FADs). FADs are human-made floating objects constructed to attract commercially valuable fish, such as tuna. FADs can be manufactured containers filled with foam or natural items like logs, but are more frequently composed of waste materials (such as damaged nets, buoys, plastic chairs, and ropes) that float, with a locator beacon attached. While FADs are sometimes anchored in waters up to 2000 meters deep, most are free-floating. Using more waste material to make a larger FAD creates more habitat for smaller fish, and after a period of weeks, months, or even years in some cases, a food chain develops, and the tuna boats return to net the associated tuna, along with significant bycatch, including turtles. The Pew Environmental Group did a study of FADs deployed by industrial tuna fisheries.[36] The Pew Group estimated that between 47,000 and 105,000 of these devices are let loose in the ocean each year.[37] The Pew report was unable to give data on the number of FADs retrieved, lost, or stolen and reused by other fishers, but stated, "Their broader

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34. E-mail from Sheri Luedtke to Vicki Diamond, Planning & Land Servs., Pierce Cnty., Wash. (Jan. 25, 2010, 12:20 PM) (on file with author); E-mail from Sheri Luedtke to Ty Booth, Planner, Pierce Cnty., Wash. (Jan. 29, 2010, 3:47 PM) (on file with author).

35. E-mail from Chulhoon Sung, Korean Broad. System, to author (Feb. 22, 2012, 11:12 PM) (on file with author).

36. Adam Baske et al., *Estimating the Use of Drifting Fish Aggregation Devices (FADs) Around the Globe*, PEW ENV'T GRP. (Nov. 30, 2012, 1:35 PM), http://www.pewenvironment.org/uploadedFiles/FADReport_1212.pdf.

37. *Id.* at 2.

ecosystem impacts and contribution to marine debris are unknown but remain serious cause for concern."[38] Some of the FADs impacts and contributions to marine debris are known, but because FADs are not required to be marked and those deploying them are not required to report their loss, making a positive correlation is difficult.

In addition to debris from FADs, there are approximately fifty-two tons of derelict fishing gear impacting the Northwest Hawaiian Islands each year.[39] The Environmental Protection Agency (EPA), in its 2011 publication *Marine Debris in the North Pacific*, states:

> Derelict fishing gear, including nets and lines, can settle on coral reefs as currents and waves transport them to shallow habitats. As the debris accumulates, it can entangle branching species of corals resulting in fragmentation and abrasion, potentially reducing habitat heterogeneity and providing open substrate for macroalgal colonization. Additionally, plastic marine debris can smother the benthos, reducing light penetration and oxygen exchange.[40]

Wildlife is also harmed, including the endangered Hawaiian monk seal, found nowhere else on the planet, protected sea turtles, and potentially cetaceans.[41] Between 1982 and 2000, over 200 Hawaiian monk seals were entangled in derelict fishing gear.[42]

The National Academies produced a document in 2008 entitled *Tackling Marine Debris in the 21st Century*. The document presented the following finding and recommendation:

> Finding: Prevention of [Derelict Fishing Gear (DFG)] begins at the source, but identifying the source may be difficult because ocean currents can transport DFG a long distance from the site of loss or discard and can involve substantial time lags. Effective gear marking is critical for identification of the sources of DFG and the fisheries that may have deployed this gear.
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> Recommendation: [The National Oceanic and Atmospheric Administration (NOAA)] should convene a workshop to explore innovative and cost-effective approaches for identification or marking of trawls, seines, gillnets, longlines, and FADs to foster gear identification. Based on this information, NOAA should develop gear marking protocols that can be used in domestic and international fisheries to provide a structured basis

38. *Id.* at 6.
39. EPA, EPA-909-R-11-006, MARINE DEBRIS IN THE NORTH PACIFIC (2011).
40. *Id.* at 9 (citations omitted).
41. *Id.* at 11-12.
42. Raymond C. Boland & Mary J. Donohue, *Marine Debris Accumulation in the Nearshore Marine Habitat of the Endangered Hawaiian Monk Seal,* Monachus schauinslandi *1999-2001*, 46 MARINE POLLUTION BULL. 1385, 1386 (2003).

> for designing programs to reduce gear loss and abandonment and increase recovery of DFG.[43]

In 2008, NOAA held a workshop on marine debris, but the only mention of the above recommendation in the "Summary Report" was a single sentence under the "Research Actions" heading: "International marking of fishing gear for tracking and identification purposes."[44] While it has been five years since the National Academies' finding and recommendation and NOAA's marine debris workshop, the author is unable to find any programs for marking gear that have been promulgated internationally.

V. LEGAL CONSIDERATIONS

In proceedings before the Shorelines Hearings Board of the state of Washington, the petitioners, the Coalition to Protect Puget Sound Habitat and an individual, appealed the permit granted to the respondents, Taylor Shellfish, Arcadia Point Seafood, and Net@Venture, Inc., by Thurston County for four shoreline substantial development permits for geoduck clam farms.[45] The hearings were held from August 12 to 16, 2013. The author appeared for the appellants as an expert witness. On October 11, 2013, the Board issued their ruling. In their findings of fact, they state:

> Planting activities will occur during the lowest tides of the summer and subsequent low tides in the fall. Arcadia plants the juvenile geoducks in four inch diameter, ten inch long off-white PVC tubes that are pushed vertically into the beach at a density of one tube per square foot. The PVC tubes protrude approximately 4 to 6 inches above the surface of the sand. The tubes are covered with a black or brown mesh cap, which is secured with a rubber band.[46]

These tubes are required for a period of one to two years to protect the juvenile clams from predators.[47] These tubes do not last in their installed condition for the life of the project. Intertidal forces lift a percentage of the tubes out of the sediment and remove the rubber bands and nets. The loss of the gear from geoduck aquaculture is evidenced by an e-mail from Wayne Palsson with the Washington Department of Fish and

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43. NAT'L RESEARCH COUNCIL OF THE NAT'L ACADS., TACKLING MARINE DEBRIS IN THE 21ST CENTURY 116 (2008), *available at* http://www.nap.edu/catalog/12486.html.

44. *Hawai'i Marine Debris Workshop Summary Report*, NAT'L OCEANIC & ATMOSPHERIC ADMIN., at C-1 (Feb. 20, 2008), http://marinedebris.noaa.gov/sites/default/files/himdapsummary.pdf.

45. Findings of Fact, Conclusions of Law, and Order at 1, Coal. To Protect Puget Sound Habitat v. Thurston Cnty., No. 13-006c (Wash. Shorelines Hearings Bd. Oct. 11, 2013).

46. *Id.* at 3.

47. *See id.* at 4.

Wildlife on September 27, 2007, which states, "Bottom Trawl Survey Estimates of Aquaculture Debris in South Sound, based upon our 2005 survey: Netting: 61,600 items[,] Tubes: 21,600[.]"[48] These tubes are not marked in any way by the operators, who maintain that marking is too difficult and an unnecessary expense.

The Board denied the appeal, in part because extrapolation was used to obtain the estimates from Wayne Palsson, and granted the permits with the following condition: "The *Washington Geoduck Growers Environmental Codes of Practices* shall be treated as containing mandatory requirements rather than optional practices."[49] However, the "Codes of Practice" only reference to escaped gear is contained in one sentence: "[A]ll unnatural debris, nets, bands, etc., are maintained and prevented from littering the waters or the beaches."[50]

Whether recommended or required, this practice is an unrealistic goal and was disputed during the *Coalition To Protect Puget Sound Habitat* hearings by numerous residents of the Sound, who brought copious amounts of the derelict gear they had collected from the shore to the hearing. Because the Codes of Practice fail to mention or require any kind of marking to determine irresponsible or accidental loss from any particular operation, all loss becomes anonymous.

VI. Types of Plastics Used in Aquaculture

At the other end of the Pacific Coast, Iván Hinojosa and Martin Thiel assessed floating marine debris in fjords, gulfs, and channels of southern Chile.[51] They note, "In recent decades, in southern Chile (Internal Sea of Chiloé and Chonos Archipelago), an explosive development of salmon and mussel aquaculture has occurred contributing 99% of the national production (occupying the 2nd and 4th place of world salmon and mussel production, respectively)."[52] They did at-sea surveys from a vessel traveling at an average speed of ten knots and found that 80% of floating marine debris was expanded polystyrene (commonly called styrofoam), plastic bags, and plastic fragments.[53]

48. E-mail from Wayne Palsson, Research Scientist, Wash. Dep't of Fish & Wildlife, to Jerry Johannes (Sept. 27, 2007, 11:33 AM) (on file with author).

49. Findings of Fact, Conclusions of Law, and Order, *supra* note 45, at 42.

50. Taylor Shellfish, *Washington Geoduck Growers Environmental Codes of Practice*, Protect Our Shoreline 8 (June 2005), http://protectourshoreline.org/taylor/8GeoduckCodesOfPractice.pdf.

51. Iván A. Hinojosa & Martin Thiel, *Floating Marine Debris in Fjords, Gulfs and Channels of Southern Chile*, 58 Marine Pollution Bull. 341 (2009).

52. *Id.* at 342 (citations omitted).

53. *Id.* at 342, 344.

While the polystyrene could not be traced to individual operations, many of the bags could. They were feed sacks used in salmon grow-out pens.[54] While not traceable, they note that polystyrene is typically used to keep mussel-growing structures at the sea surface and may release debris into the marine environment.[55] They point out that in another area where oysters are cultured, Hiroshima Bay, Japan, 99% of shoreline debris was styrofoam.[56] Korean investigators suggested, "[T]he huge quantity of [polystyrene] on S[outh] Korean beaches is generated by aquaculture activities in coastal waters."[57] These pieces of polystyrene were larger chunks broken off by mechanical means, but it is also known that boring crustaceans on polystyrene floats can expel millions of microplastic particles.[58]

Of all the major types of plastic used around the world, polystyrene leaves the factory with 8 to 200 times more priority aromatic hydrocarbon pollutants.[59] The higher amount of pollutants has been attributed to the "aromaticity of the styrene monomer."[60] Styrene is a hydrocarbon monomer in the benzene family, which contains many toxic chemicals that volatilize readily. The polymerization of the styrene monomer into the plastic, polystyrene, is an industrial practice. The industrial practice never polymerizes 100% of the styrene monomer used in the process, and the resulting polystyrene plastic contains a small percentage of the toxic styrene monomer. "The mixture of the [polystyrene] monomer itself, chemicals from the manufacturing process, and those sorbed from the environment may act as a multiple stressor to several species that ingest [polystyrene] debris."[61] The enormous amount of uncovered expanded polystyrene docks and floats used in aquaculture and its tendency to readily fragment means that untold trillions of particles the size of plankton and fish eggs are becoming a part of the marine food web.

Polystyrene has competition in the race to be the worst threat to the marine environment from plastics. The other major plastics used in aquaculture that threaten the marine environment are the olefins,

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54. *Id.* at 347-48.
55. *Id.* at 347.
56. *Id.* at 346.
57. *Id.* at 347.
58. Timothy M. Davidson, *Boring Crustaceans Damage Polystyrene Floats Under Docks Polluting Marine Waters with Microplastic*, 64 MARINE POLLUTION BULL. 1821, 1825 (2012).
59. Chelsea M. Rochman et al., *Polystyrene Plastic: A Source and Sink for Polycyclic Aromatic Hydrocarbons in the Marine Environment*, 47 ENVTL. SCI. & TECH. 13,976, 13,978 (2013).
60. *Id.*
61. *Id.* at 13,983 (citations omitted).

polypropylene and polyethylene, and the chlorinated plastic, PVC. As discussed above, PVC tubes are used in clam aquaculture. PVC has been called "the poison plastic" and is not recommended for use with drinking water.[62] PVC contains a small percentage of nonpolymerized vinyl chloride capable of leaching into liquids with which it comes in contact. The EPA's "maximum contaminant level goal" for vinyl chloride is zero.[63] Such persistent, bioaccumulative toxic substances are linked with endocrine hormone disruption, "decreased fish populations and reduced species evenness and richness."[64]

Polypropylene ropes, another threat to the marine environment, are used extensively in aquaculture because of their low cost and the fact that they float.[65] In addition to ropes, polyethylene is used for floats, as well as tubes and disks that space apart or support oysters and mussels in grow-out facilities.[66]

The types of plastics used in aquaculture and their effects in the Pacific have been thoroughly studied. Both polypropylene and polyethylene have been examined extensively at the Tokyo University of Agriculture and Technology by Dr. Hideshige Takada and colleagues. They have found high levels of pollutants in derelict polypropylene and polyethylene pellets stranded on beaches, with older plastics showing the highest levels.[67] Dr. Lorena Rios of the University of Wisconsin—Superior has studied polymers collected from the North Pacific Gyre, Hawaii, and coastal California. Her research found aromatic hydrocarbon pollutants present in all samples.[68] The legacy pollutants included the pesticide dichlorodiphenyltrichloroethane (DDT) and various polychlorinated biphenyls (PCBs).[69] Dr. Chelsea Rochman and colleagues studied polyethylene exposed to seawater in San Diego Bay, California, and then fed the polyethylene to fish in a laboratory.[70] They

62. *See Basic Information About Vinyl Chloride in Drinking Water*, EPA, http://www.water.epa.gov/drink/contaminants/basicinformation/vinyl-chloride.dfm (last updated May 21, 2012).

63. *Id.*

64. Rochman et al., *supra* note 8, at 1 (citations omitted).

65. *See* WASH. SEA GRANT, *supra* note 25, at 8-9.

66. *Id.* at 10-11.

67. *See* Satoshi Endo et al., *Concentration of Polychlorinated Biphenyls (PCBs) in Beached Resin Pellets: Variability Among Individual Particles and Regional Differences*, 50 MARINE POLLUTION BULL. 1103, 1108, 1112 (2005); Yukie Mato et al., *Plastic Resin Pellets as a Transport Medium for Toxic Chemicals in the Marine Environment*, 35 ENVTL. SCI. & TECH. 318, 320 (2001).

68. Lorena M. Rios et al., *Persistent Organic Pollutants Carried by Synthetic Polymers in the Ocean Environment*, 54 MARINE POLLUTION BULL. 1230, 1236 (2007).

69. *Id.* at 1236.

70. Rochman et al., *supra* note 8, at 2.

confirmed that the exposed plastics had absorbed hazardous chemicals and that the studied fish had pathological changes to their livers, including one fish that developed liver cancer.[71]

VII. CONCLUSION

Unmonitored and unregulated aquaculture activities around the world are poisoning and choking the marine environment with their lost and derelict plastic gear. Alternative plastics that will biodegrade in the marine environment exist, such as polyhydroxyalkanoate (PHA), which could be used for the PVC tubes in clam aquaculture, but cost twice as much as PVC.[72] Support for aquaculture by governments, rightly concerned with depletion of the marine food web by wild capture, needs to include funding for monitoring, researching, and marking plastic and other gear that is safe for people, the environment, and wildlife. At the present time, it does not appear possible to introduce any conventional plastic into the marine environment without harmful consequences.

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71. *Id.* at 4-5.
72. Interview by Charles Moore with Richard Eno, Former CEO, Metabolix, in Cambridge, Mass. (Dec. 3, 2010).